

Opinion of Dr. Richard J. Lee

In the matter of

In Re: W. R. Grace & Co., et al

Prepared for

W. R. Grace & Co.
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I. Summary

The purpose of this report is to review the mineralogy, form, and exposure potential of the amphibole particles found in installed Zonolite Attic Insulation (ZAI) manufactured and sold by W. R. Grace & Co. Additionally we have reviewed and offer comments on the testing results reported by Claimants' experts and the opinions expressed by those experts. Based on our review of the literature, our own experience and studies, studies by W. R. Grace, studies by Claimants' experts in this matter and the Barbanti v. W. R. Grace & Co. matter (Barbanti), EPA reports related to Libby, Montana, and the World Trade Center, the history of EPA activity in Minnesota, the findings of OSHA in 1992, the findings of the Consumer Product Safety Commission in 2000¹, and the history of the regulations and methods for analyzing asbestos, it is our opinion within a reasonable degree of scientific certainty that:

- 1) Phase Contrast Microscopy (PCM) measurements of airborne fiber concentrations in atmospheres where ZAI is being manipulated, handled, or removed by a homeowner significantly overestimate potential "*asbestos*" fiber concentrations. In Claimants' experts' airborne "*asbestos*" fiber counts, the average reduction would be more than three-fold, simply by excluding non-mineral fibers such as hair, cotton, and cellulose.
- 2) *Asbestos* is a commercial term applied to the occurrence (in sufficient quantity to make their extraction and beneficiation economically viable) of *asbestiform* minerals, which are minerals with physical and thermal properties of

¹ Consumer Product Safety Commission (2000). "CPSC Releases Test Results on Crayons", press release no. 00-123, June 13, 2000.

potential commercial significance in applications requiring flexibility, thermal stability or high tensile strength. *Asbestiform* minerals are naturally formed in a fibrous, flexible form with a high aspect ratio known as fibers.

3) *Asbestos* minerals have non-asbestos analogs called *cleavage fragments*. When finely divided or crushed, *cleavage fragments* may have a similar appearance to asbestos fibers, but are generally thicker and shorter than asbestos fibers and have other distinguishing characteristics.

4) Regulatory methods are and have been expressly designed to measure the concentrations of asbestos fibers and explicitly cite the "asbestiform varieties of ... [amphibole minerals]" in air, water, or bulk samples, not the concentration of *cleavage fragments*.

5) Claimants' experts misrepresent the OSHA position by failing to acknowledge that in 1992 OSHA explicitly excluded amphibole *cleavage fragments* from their regulations.

6) Claimants' experts' TEM analysis is flawed because it included non-asbestiform *cleavage fragments* in their "*asbestos*" count, thereby inflating their "*asbestos*" results.

7) Contrary to Claimants' experts' assertions, the majority of the amphiboles in ZAI are neither asbestiform nor respirable.

8) Claimants' estimated concentrations would be reduced by at least ten-fold if the concentration of non-asbestiform *cleavage fragments* in their samples were excluded from their "*asbestos*" count.

9) Exposure measurements made by RJ Lee Group and two groups of Claimants' experts using PCM methodology and adjusted for the quantities of non-mineral fibers and *cleavage fragments*, indicate airborne asbestos concentrations would have been comparable to or below relevant standards.

10) Evaluation of Claimants' experts' own surface dust data demonstrates that their use of indirect preparation significantly breaks up the mineral particles in the samples. The surface dust particles are smaller than the airborne particles, thus demonstrating the disaggregating effect of indirect preparation.

11) Neither the ASTM surface dust method(s) nor the indirect preparation technique is generally accepted as a reliable indicator of past or potential future airborne exposures. Results derived from the analysis of samples prepared using an indirect preparation technique cannot be used for risk evaluation.

12) There is no reliable scientific evidence that ZAI is unsafe.

II. Qualifications

Dr. Richard J. Lee obtained a Bachelor of Science degree in physics from the University of North Dakota in 1966 and a Ph.D. in theoretical solid state physics from Colorado State University in 1970. He then went to Purdue University as an Assistant Professor in physics

where he taught courses on the principles of optical microscopy. He received tenure at Purdue in less than two years.

In 1973, Dr. Lee went to work for United States Steel, first as a research scientist and thereafter, as director of their physics and electron microscopy department in the Technical Center. He remained at the United States Steel Research Center until 1985. While at United States Steel, he analyzed a wide range of materials and was employed by NASA to analyze moon rocks brought back by the Apollo missions.

During his tenure at USS Research, Dr. Lee was responsible for developing the first techniques for quantitatively identifying amphibole asbestos fibers and cleavage fragments by a combination of transmission electron microscopy and energy dispersive X-ray analysis. He participated in the original ASTM committee that developed and evaluated the first TEM methods for preparing samples of air, bulk and water for the determination of asbestos content. Dr. Lee was the first scientist to develop methods for distinguishing asbestos amphiboles from cleavage fragments using transmission and scanning electron microscopy.

Since 1985, Dr. Lee has been President of a company now known as RJ Lee Group, Inc., ("RJ Lee Group") which has its principal office in Monroeville, Pennsylvania, and laboratories in San Leandro, California; and Manassas, Virginia. RJ Lee Group provides research, analytical and consulting services relating to materials characterization. Materials characterization of bulk building materials, also referred to as "constituent analysis", involves analyzing a sample of material using various techniques to identify and quantify the components of that material.

Dr. Lee has a long history of scientific consulting and service for government agencies, including the EPA. RJ Lee Group's laboratory serves as a quality assurance and referee

laboratory on a number of EPA programs. RJ Lee Group's laboratory performed the analyses for the EPA's major study on airborne levels of asbestos in public buildings. Dr. Lee has participated in the development by the EPA of analytical methods and procedures for asbestos analyses. The EPA requested that he personally participate in several projects, including the drafting of the portions of the EPA AHERA regulations governing air sample analysis after abatement.

RJ Lee Group also performs analyses for the United States Navy, the United States Army and the United States General Services Administration. Dr. Lee developed a program to determine the cause of failure in components of the guidance system in the Trident missile for the Department of the Navy.

RJ Lee Group's laboratory has also performed microscopic analyses for the State of California Air Resources Board when that agency performed testing of the air in major cities in the State of California to determine the presence of asbestos.

Dr. Lee is now engaged in and specializes in materials characterization, which is the science that uses a variety of analytical techniques to determine the identity and amount of each component of a material. He has performed materials characterization analyses on many samples of vermiculite produced from different sources for over 15 years. He is familiar with all methods of microscopy that are commonly used in characterizing asbestos or identifying and quantifying asbestos, including optical microscopy, scanning electron microscopy and transmission electron microscopy. He is also familiar with all known methodologies, from air sampling to dust sampling, with respect to asbestos. He has worked extensively with, and is an expert in, analytical techniques, including light and electron microscopy, materials

characterization, asbestos air, bulk, and dust samples, and methods of evaluation. He has also served as an expert witness in litigation involving asbestos in buildings and ZAI and has testified in state and federal courts.

Dr. Lee is familiar with airborne levels of asbestos fibers both in buildings and in outdoor air, the sources of asbestos in the outside or ambient air, scientific knowledge and techniques regarding the measurement of levels of asbestos in the air, the development and use of the technology to measure both airborne levels of fibers and levels in materials samples, and the standards and methods used for air sampling. He has been involved in analyzing and producing bodies of air sampling data for EPA and other governmental and private entities including analysis of samples taken in an ongoing nationwide study of airborne levels in buildings and his analysis of air samples taken in an EPA-sponsored study in Texas.

He is also familiar with the history of standards governing asbestos including the current standards, regulatory positions and philosophies, different types of asbestos fibers, asbestos fiber levels as reported in the literature, as well as his own work concerning buildings with asbestos-containing materials.

Dr. Lee's fee for consulting, depositions, and trial appearances is \$350 per hour.

III. Background

At issue is the potential risk to homeowners or contractors handling, manipulating, removing, or simply having a product known as Zonolite Attic Insulation (ZAI) in these homes. The product consists of lightweight expanded vermiculite, ordinarily between 2 and 10 mm in diameter and 5 – 15 mm in length. ZAI was manufactured from vermiculite concentrate shipped

from Libby, Montana to expansion plants around the country where it was thermally expanded in furnaces, bagged, and sold through distributors to contractors and homeowners for use as attic insulation.

The product contains sub-calcic, sodic, tremolitic amphiboles² that have become known as "Libby Amphiboles". These were present in the mine but were not completely removed in the beneficiation process and comprised generally 0.1–1 percent by weight of the ZAI (see Section V of this Report). Generally these amphiboles are 2-5 mm in size. Minute quantities of these amphiboles are present in the product as a dust (<100 micrometers in length), along with fine vermiculite and other accessory minerals. While a small portion of this material is a fibrous asbestos amphibole; most of the material is a non-asbestos form of amphibole (i.e., *cleavage fragments*). In other words, the dust consists of broken pieces of the processed material. The amount of respirable Libby Amphibole in the dust is minute, varying from 0.0001 to 0.1 per cent by weight of the product.

IV. Applicable Standards and Testing Protocols

A. Asbestos and Cleavage Fragments

The term "asbestos" is a commercial term that refers to naturally occurring fibrous minerals that are economically exploitable. "Asbestos" is defined in the Code of Federal Regulations (29 CFR 1910.1001, 40 CFR 763.83, 40 CFR 61.141) as chrysotile, amosite, crocidolite and the asbestiform varieties of tremolite, anthophyllite and actinolite, as well as any

² A. L. Boettcher (1966). "The Rainy Creek Igneous Complex Near Libby, Montana", PhD Thesis, The Pennsylvania State University, June 1966.

of these minerals that have been chemically treated and/or altered. The terms “tremolite asbestos,” “anthophyllite asbestos” and “actinolite asbestos” are also used to refer to asbestiform varieties of these minerals.

Asbestos minerals belong to two mineral families: the serpentines and the amphiboles. Tremolite, anthophyllite, and actinolite are types of amphibole minerals. They differ in their chemical composition, and can grow in either an asbestiform or cleavage (non-asbestiform) manner. The habit of a mineral is the shape or form a crystal or aggregate of crystals take on during crystallization and is dependent on the existing environmental/geological conditions at the time of formation. Asbestiform minerals are formed through unidirectional crystalline growth that produces long thin fibers. The narrow width and long lengths of asbestos provide flexibility and high tensile strength.

Unlike asbestos, cleavage amphibole minerals grow in three dimensions to produce the non-fibrous (massive) form of the same mineral. When non-asbestiform cleavage minerals such as amphiboles are crushed, fragments are cleaved away from the main crystal mass, a process that produces “cleavage fragments”. The massive mineral will tend to fracture along sets of systematic planes within the mineral crystal, and some long thin fragments may result, although the majority of the fragments will be short, non-fibrous particles. These cleavage fragments may have a similar microscopic appearance to that of true asbestos fibers, although distinguishing characteristics include size, optical extinction characteristics, and morphology.

Cleavage fragments have more surface defects, a higher susceptibility for acid dissolution, and a different surface charge than do asbestos fibers. Cleavage fragments, compared to asbestos fibers, are weak and are not flexible (more brittle).

Populations of cleavage fragments and populations of asbestos fibers can be distinguished from one another when viewed as a whole, because cleavage fragments are likely to be thicker and shorter than asbestos particles and will therefore have lower aspect ratios. Individual particles may be more difficult to classify. Table 1 lists selected references that discuss the nature of asbestos fibers and cleavage fragments.

Asbestiform fibers have been defined as those exhibiting characteristics of: (a) high aspect ratios (usually 20:1 to 100:1 or higher); (b) curvature; and (c) fiber bundles with splayed ends. Asbestiform fibers can occur in bundles of parallel fibers or in matted masses of fibers and fiber bundles. Typically, individual fibers have width dimensions of less than 0.5 μ m. Competent microscopists can tell the difference between asbestos and cleavage fragments.

Since the early 1970's, the question of whether to count asbestos and non-asbestos amphiboles in measurements of airborne asbestos concentrations has been the subject of controversy. The issue took root in the early 1970's. Fibers believed to be amphibole asbestos discharged as part of taconite mining tailings were found in samples of Lake Superior water³. The amphiboles in question included grunerite and actinolite, closely related to the amphiboles present in ZAI.

³ W. Brice and M. Berndt (2003). "Reserve Mining and the Asbestos Case", presentation at International Symposium on the Health Hazard Evaluation of Fibrous Particles Associated with Taconite and the Adjacent Duluth Complex, St. Paul, MN, March 30 – April 1, 2003.

Some thirty years later, a number of epidemiological and animal studies have found no evidence that the non-asbestos amphibole cleavage fragments from the iron region of Minnesota produce mesothelioma or other asbestos disease⁴.

Claimants' experts contend that the presence of any amphibole in ZAI renders it unsafe because sufficient airborne dose (exposure to an airborne concentration over a given period of time) of a particular fibrous form of amphibole (known as asbestos) causes disease. Claimants' experts include in the measurement of the airborne concentration any amphibole particle that meets a particular shape and length criteria, regardless of whether it is in fact asbestos. They erroneously contend that there is no mineralogical or regulatory distinction and that applicable regulations intend to regulate all amphiboles if they meet the definition of a fiber.

B. Cleavage Fragments Should be Excluded from "Asbestos" Counts

In 1992, OSHA examined the history and epidemiology of non-asbestos amphiboles (in particular tremolite) and concluded that they should not be regulated and should not be included in "asbestos" counts⁵. In the Preamble to the 1992 Final Rule on Occupational Exposure to Asbestos, Tremolite, Anthophyllite and Actinolite (Intro to 29 CFR Parts 1910 and 1926), OSHA removed cleavage fragment tremolite, anthophyllite and actinolite (ATA) from the scope of asbestos regulations. The Preamble discusses at length the reasoning for this removal of cleavage ATA.

⁴ W. Brunner, A. Williams, A. Bender (2003). Exposures to Commercial Asbestos in Northeastern Minnesota Iron Miners who Developed Mesothelioma, draft report, Minnesota Department of Health, Chronic Disease and Environmental Epidemiology Section.

⁵ The Preamble to the 1992 OSHA ruling can be found on the Internet at http://www.osha.gov/pls/oshaweb/owasrch.search_form?p_doc_type=PREAMBLES&p_toc_level=1&p_keyval

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OSHA's discussion includes both an analysis of the medical evidence regarding the effects of asbestiform and cleavage ATA as well as the feasibility of analytically distinguishing between the two forms. OSHA stated that asbestos and cleavage ATA appeared to be distinguishable mineral entities on a population basis, and in most instances on a particle basis. The Preamble states that differences in biologic effect between asbestos and its cleavage analogues are likely related to the distinctions that define the two groups as separate mineral entities. To distinguish cleavage ATA from asbestos, OSHA acknowledges and allows the use of differential counting with its current approved methodology. Cleavage fragment ATA can be excluded from asbestos concentrations if sufficient evidence to do so can be shown through the various differential counting techniques.

Table 2 lists relevant citations from regulations and analytical methods showing the intent of all of the regulations to regulate asbestos minerals – not cleavage fragments (the nonasbestos variety of the amphibole minerals). A similar listing has been created by Lowers and Meeker⁶.

As stated, amphibole minerals can form in two manners – as fibers or fiber bundles, loosely cemented together, and as crystals bound together by strong, ionic, crystallographic forces⁷. In the first case, the fibers may have commercial value and may readily be separated into respirable asbestos fibers of high aspect ratio – the basis of the asbestos textile and other

Continued from previous page

ue=Asbestos~(1992~Original)&p_status=CURRENT&p_search_str=&p_text_version=FALSE. See Chapter IV.

⁶ H. Lowers and G. Meeker (2003). "Tabulation of Asbestos-Related Terminology", US Geological Survey, Open File Report 02-458, available at: <http://pubs.usgs.gov/of/2002/ofr-02-458/>.

⁷ W. Campbell, E. Steel, R. Virta, and M. Eisner (1979). "Relationship of Mineral Habit to Size Characteristics of Tremolite Cleavage Fragments and Fibers", U.S. Department of the Interior, Bureau of Mines, Report of Investigation No. 8367.

asbestos industrial applications. In the second case, the crystals may be broken into fragments which have a similar appearance to asbestos fibers when finely divided, but which have no economic value because they cannot be separated into flexible, high-aspect ratio fibers that can be woven or otherwise manipulated⁸.

More recently, the Consumer Product Safety Commission examined the issue of tremolite in color crayons and concluded that cleavage tremolite and anthophyllite presented, at most, an insignificant risk⁹.

Beyond the distinction between asbestiform fibers and cleavage fragments, it is widely recognized that the amphibole fibers of toxicological significance to human health are long and thin. In the 1970's, Dr. Merle Stanton studied a large number of mineral fibers and concluded that fibers longer than eight micrometers and less than 0.5 micrometers in diameter were far more potent than shorter or thicker fibers¹⁰. This was reinforced by numerous studies during the 70's and 80's. Today, the so-called Stanton hypothesis has withstood the test of time. In fact, the latest EPA-sponsored risk assessment¹¹ finds the medically significant (risk) fibers are those that are longer than 40 micrometers and thinner than 0.3 micrometers, a size and shape rarely found in cleavage fragments.

⁸ R. Virta and E. Mann (1994). "Asbestos", in *Industrial Minerals and Rocks*, 6th ed., D. Carr, editor, Society for Mining, Metallurgy, and Exploration, Inc., p. 97 - 124.

⁹ Consumer Product Safety Commission (2000). "CPSC Releases Test Results on Crayons", press release no. 00-123, June 13, 2000.

¹⁰ M. F. Stanton, M. Layard, A. Tegeris, E. Miller, M. May, E. Morgan, and A. Smith (1981). "Relation of Particle Dimension to Carcinogenicity in Amphibole Asbestos and Other Fibrous Minerals," *Journal of the National Cancer Institute*, 67, p. 965-975.

¹¹ D. Berman and K. Crump (1999). "Methodology for Conducting Risk Assessments at Asbestos Superfund Sites, Part 2: Technical Background Document", prepared for Kent Kitchingman, U.S. EPA Contract No. 68-W9-0059, Work Assignment No. 59-06-D800, Feb. 15, 1999.

The mineralogical distinction between asbestos and cleavage fragments is well established. The intent of the regulations is "to count those asbestos particles meeting the definition of a fiber, and not non-asbestiform particles such as cleavage fragments."¹² The epidemiological data demonstrate that non-asbestos amphiboles do not behave as asbestos and that the asbestos particles of significance are generally outside the size range found in cleavage fragments.

Thus, of the airborne amphibole particles that are asbestos and meeting the dimensional aspects of regulated fibers should be included in the *asbestos* count. In this case, this would reduce the Claimants' TEM asbestos counts at least ten-fold.

C. Bulk Sample Collection Equipment and Analysis

Bulk samples (1 to 2 grams) may be taken with tube or cork borer sampling devices and are placed in sealed containers for storage or transport to the laboratory. Samples may be prepared by chemical reduction of the matrix, drying, or heating to produce a powder that is sufficiently fine to fit under a glass cover slip for microscopic examination. Forceps may also be used to take samples from several parts of a bulk material. Such samples are placed directly on microscope slides.

Optical microscopy (and polarized light microscopy (PLM), in particular) is a technique used to identify the minerals in a bulk specimen. Originally used for rock and ore examination, optical microscopy is now used for determining the mineral content of numerous materials,

¹² D. Crane (1988). "Asbestos in Air", OSHA Analytical Methods Manual, ID-160, available at www.osha.gov/dts/sltc/methods/inorganic/id160/id160.html, July, 1988.

including bulk building materials and soils. PLM is very subjective for asbestos at low concentrations¹³. To improve the quantitation, EPA now requires that samples with low levels of asbestos (usually less than 10 percent) be point-counted¹⁴.

In 1982, the EPA issued an Interim Method that created a uniform procedure for mineral identification and quantification of asbestos in bulk building materials (currently at Appendix E to Subpart E, 40 CFR Part 763). The original version of the method required the use of "point counting" to quantify the asbestos content of the material. In its current version, the method permits either point counting or a visual estimation technique for quantitation.

Included with the methods and regulations are descriptions of the material being evaluated. As shown in Table 2, EPA and OSHA clearly regulate and analyze for regulated asbestiform minerals; they do not include the non-asbestiform cleavage minerals.

D. Air Sample Collection Equipment and Analysis

1. Phase Contrast Microscopy

In the early 1960's, air filters began to achieve acceptance for the collection of the airborne particulate. These early studies were first conducted in the United Kingdom and later in the United States. Protocols for the method were established by the Public Health Service and NIOSH for the use of PCM. Following studies that showed variability in results due in part to varying qualities of the microscopes, NIOSH published the 7400 method in 1984. This

¹³ R. Perkins, B. Harvey, and M. Beard (1994). "The One Percent Dilemma", *EIA Technical Journal*, 2, p. 5 – 10.

¹⁴ Code of Federal Regulations (2002). National Emission Standard For Asbestos, 40 CFR, Part 61.141. Definition for Friable Asbestos.

method¹⁵ specified sample collection procedures, material (filter and microscope), quantities, and counting protocols. PCM, under NIOSH 7400, does not differentiate between asbestos and non-asbestos fibers, but counts all fibers that are longer than 5 μm and have a minimum aspect ratio of 3:1.

PCM is not an appropriate method for estimating exposure in a dusty environment such as an attic where the accumulation of non-mineral fibers (such as cotton, hair, etc.) meeting the PCM counting criteria is known to occur over time. The amount of this overestimate can be evaluated by comparing the TEM and PCM counts in the various studies in this matter. For example, in Claimants' experts' studies, elimination of the non-mineral fibers from the PCM count would result in more than a three-fold reduction in worker task concentrations. In the Lees and Mlynarek study (see section VI of this Report), elimination of the non-mineral fibers resulted in a four-fold reduction in such concentrations.

2. Transmission Electron Microscopy

Beginning with early studies of particulates¹⁶, electron microscopes were used to examine the crystal structure of the asbestos minerals, particularly that of chrysotile. By the mid to late 1960's, transmission electron microscopy (TEM) was being used, notably by Pooley and Henderson in the United Kingdom, for the study of mineral particles in lung tissue¹⁷. Similar

¹⁵ NIOSH Manual of Analytical Methods, NIOSH 7400, "Fibers". The current version as listed as "Asbestos and Other Fibers by PCM", issue 2, August 15, 1994. available at <http://www.cdc.gov/niosh/nmam/pdfs/7400.pdf>.

¹⁶ D. A. Fraser (1953). "Absolute method of sampling and measurement of solid airborne particulates – combined use of the molecular filter membrane and electron microscopy", *Archives of Industrial Hygiene and Occupational Medicine*, 8, p. 412.

¹⁷ I. M. Stewart (1989). "History of TEM Analysis for Asbestos", personal communication.

work was pursued by Mt. Sinai School of Medicine, in New York City, and by the late 1960's, TEM had been used for the study of environmental samples.

The first recognized EPA TEM procedure for air samples was written by Samudra, et al¹⁸. That provisional method specified sample collection and preparation procedures, but did not specify counting rules. Recognizing the limitations of the provisional TEM method, IIT Research Institute was contracted by the EPA to draft a revised method. The initial discussion of the draft method was presented at a conference held at the National Bureau of Standards in 1980; the final draft¹⁹ was never officially published by the EPA, but is still widely used. Among the improvements over the provisional method was the specification of counting rules – defining what constitutes a fiber and how it should be counted. This draft method (called Yamate, EPA Level II, or Level II) was used by Claimants' experts in their tests (see Appendix E to the Zonolite Insulation Exposure Studies by Ewing, et. al, listed next to "Analysis Type").

The first fully reviewed air protocol was a TEM method for testing the cleanliness of air in schools following abatement actions. Under the authority of the Asbestos Hazard Emergency Response Act (AHERA), the EPA developed a rapid TEM method²⁰ for use in clearance testing at abatement sites. The method specified sample collection procedures and required a direct transfer preparation method. To reduce the analysis time, the method did not require recording

¹⁸ A. V. Samudra, C. F. Harwood, and J. D. Stockham (1977). "Electron Microscope Measurement of Airborne Asbestos Concentrations: A Provisional Methodology Manual", US Environmental Protection Agency, Report EPA 600/2-77-178, August 1977.

¹⁹ G. Yamate, S. C. Agarwal, R. D. Gibbons (1984). "Methodology for the Measurement of Airborne Asbestos by Electron Microscopy", IIT Research Institute, Contract No. 68-02-3266, July 1984. The method is referred to as the "Yamate Method" and also as "EPA Level II".

²⁰ "Interim Transmission Electron Microscopy Analytical Methods – Mandatory and Nonmandatory – And Mandatory Section to Determine Completion of Response", Federal Register, 52, p. 41857 – 41897, October 30, 1987.

of fiber dimensions, but did require listing the fibers as either greater than 5 μm or less than 5 μm in length. One significant change over the Draft Method was the increase in minimum aspect ratio from 3:1 to 5:1. A minimum length for asbestos fibers (0.5 μm) was specified for the first time to improve the reproducibility of fiber counts. The method is widely used in the United States.

Not all airborne fibers are asbestos and, in 1989, NIOSH issued its first TEM asbestos method, NIOSH 7402, which was designed for use in conjunction with PCM (NIOSH 7400) to allow determination of the proportion of countable fibers present in mixed fiber environments that were actually asbestos. The method²¹ used a magnification comparable to the magnification used in the optical microscope, counted only fibers longer than 5 μm , wider than 0.25 μm , and had an aspect ratio of at least 3:1. OSHA permits the use of the NIOSH 7402 method when analyzing air samples for OSHA compliance purposes (when performed in conjunction with PCM)²².

3. Direct Versus Indirect Sample Preparation

The direct preparation procedure is the only correct analytical technique for any risk assessment. As described in the latest proposed version of the EPA risk method²³, only a directly prepared sample can be used to determine the exposures for risk analyses. Indirect

²¹ NIOSH Manual of Analytical Methods, "Asbestos by TEM", Method 7402, May 15, 1989. Available at <http://www.cdc.gov/niosh/nmam/pdfs/7402.pdf>.

²² D. Crane (1998). Letter to Jim Johnston, US Department of Labor, Occupational Safety & Health Administration, June 24, 1998.

²³ D. Berman and K. Crump (1999). "Methodology for Conducting Risk Assessments at Asbestos Superfund Sites, Part 2: Technical Background Document" prepared for Kent Kitchingman, U.S. EPA Contract No. 68-W9-0059, Work Assignment No. 59-06-D800. The proposed risk method can be found at <http://www.epa.gov/oerrpage/superfund/programs/risk/asbestos/method.htm>.

preparation takes large, non-respirable particles captured on an air filter and breaks the particles into numerous "respirable" particles.

Current TEM air analytical methods specify the use of a direct preparation procedure. A direct procedure is essentially one where the filter is coated with a layer of evaporated carbon, the filter is dissolved, and the carbon film (containing the trapped particles) is inserted into the microscope. During an indirect preparation procedure, the filter is manipulated in such a way as to produce a suspension of particles in a transfer medium (usually water), which is then filtered onto a new filter. The redeposit filter is then prepared for examination using the direct transfer procedure. The manipulation of the original filter to produce the suspension is usually either ashing followed by sonication of the suspended ash or sonication of the filter in a bath of liquid.

The purpose of the indirect preparation procedure is to remove interfering materials (such as organic matter or acid-soluble minerals such as carbonates or gypsum) from the sample and to disperse the remaining material evenly over a new filter to permit improved visual inspection of the fibers. However, the indirect preparation procedure liberates asbestos from bound matrices, splits fiber-bundles into individual fibers, and fractures the fibers into shorter, more numerous fibers, thus artificially inflating the number of respirable particles that were originally in the sample.

When the analysis is being performed for a mass determination, an increase in the number of counted fibers is not significant provided accurate dimensions of the fibers can be obtained for the mass calculation. However, when the result is to be expressed as a number concentration of airborne fibers, the indirect preparation procedure produces results that are artificially biased high. Early TEM method development work recognized this effect – "The

ultrasonic treatment not only dispersed and deagglomerated the particulate matter, but also broke the asbestos into shorter and finer particles, even approaching formation of individual fibrils of colloidal dimensions.”²⁴

The EPA has reported that the indirect preparation procedure results in uncontrolled and non-reproducible increases in the observed fiber concentration²⁵. Other researchers have reached similar conclusions²⁶; The Health Effects Institute-Asbestos Research (HEI-AR)²⁷ provided a description of the problem. Campbell, et al²⁸ provide photographic evidence of the type of breakage that will occur when tremolite fractures across the long axis of the crystal.

To illustrate the effect of the indirect preparation, a bundle of asbestiform tremolite (from an eastern U.S. quarry) was subjected to a standard indirect preparation procedure. The procedure involved placing the bundle into 100 ml deionized water (pH 4 adjusted using acetic acid) and sonicating for 3 minutes in a standard laboratory ultrasonic bath (CrestSonic Model

²⁴ U.S. Environmental Protection Agency (1977). "Comparison of Ambient Asbestos Levels Determined by Various Laboratories", Environmental Monitoring and Support Laboratory, Office of Research and Development, at p. 10.

²⁵ J. Chesson and J. Hatfield (1990). "Comparison of Airborne Asbestos Levels Determined by Transmission Electron Microscopy (TEM) Using Direct and Indirect Transfer Techniques", U.S. Environmental Protection Agency, EPA Report EPA 560/5-89-004, March 1990.

²⁶ R. J. Lee, D. R. Van Orden, G. R. Dunmyre, and I. M. Stewart (1996). "Interlaboratory Evaluation of the Breakup of Asbestos-Containing Dust Particles by Ultrasonic Agitation", *Environmental Science & Technology*, 30, pp. 3010 - 3015.

R. J. Lee, T. V. Dagenhart, G. R. Dunmyre, I. M. Stewart, and D. R. Van Orden (1996). "Response to Comment on 'Effect of Indirect Sample Preparation Procedures on the Apparent Concentration of Asbestos in Settled Dusts'", *Environmental Science & Technology*, 30, pp. 1405 - 1406.

R. J. Lee, T. V. Dagenhart, G. R. Dunmyre, I. M. Stewart, and D. R. Van Orden (1995). "Effect of Indirect Sample Preparation Procedures on the Apparent Concentration of Asbestos in Settled Dusts", *Environmental Science & Technology*, 29, pp. 17 - 1736.

²⁷ Health Effects Institute - Asbestos Research (1991). Asbestos in Public and Commercial Buildings: A Literature Review and Synthesis of Current Knowledge, Health Effects Institute - Asbestos Research, Cambridge, MA, pp. 4-24 and 4-26.

²⁸ W. J. Campbell, E. B. Steel, R. L. Virta, and W. H. Eisner (1979). "Relationship of Mineral Habit to Size Characteristics for Tremolite Cleavage Fragments and Fibers", U.S. Department of the Interior, Bureau of Mines, Report of Investigation 8367, Figure 11.

275-D). An aliquot of the resulting suspension was filtered through a standard mixed cellulose ester filter that was subsequently prepared for examination on the TEM. Figure 1a of this Report shows an optical image of the bundle prior to preparation; Figure 1b shows a TEM micrograph of a grid opening in the TEM. The single bundle was reduced to tiny fibers that would be counted using any analytical protocol.

To further document the effect of indirect preparation, a piece of amphibole asbestos ore from Libby Montana was sonicated in an ultrasonic bath (similar to one that would be used by a jeweler to clean rings) for 3 minutes, a time period usually used in indirect preparation. Following sonication, the entire suspension was deposited on a filter and examined in the TEM. The original amphibole bundle was broken into more than 10,000,000 individual particles.

The effect of indirect preparation is explicitly illustrated by the data presented by Claimants' experts. Air filters were collected and analyzed using a direct preparation procedure. Surface dust samples were collected and prepared using an indirect preparation procedure. Because dust represents material that settled onto surfaces, it (by definition) represents structures that are longer and wider than airborne particles. Figures 2 and 3 compare the length and width of the airborne and surface dust particles.

These graphs show the counted dust amphibole fibers are both shorter and thinner than those found in the air. This can only happen as a result of the sonication process used during the indirect preparation procedure.

4. IRIS Premise and Process

EPA risk assessment is performed using the Integrated Risk Information System (IRIS) methodology. IRIS requires the use of PCM as the primary assessment tool for airborne asbestos fiber levels. Because the epidemiology studies upon which IRIS is based are all related directly to commercial asbestos exposures, IRIS calls for the counting of asbestos fibers. The appropriate methods to use under IRIS are the same as prescribed by OSHA: analyze the samples by PCM using NIOSH 7400, and adjust for the percentage of fibers that are asbestos as determined by NIOSH 7402.

V. Amphiboles in ZAI

The amphiboles in ZAI occur in two size categories. The dominant portion is in a size range typical of the smaller end of the vermiculite in the expanded product. The remainder is a fine dust. As described below, samples of ZAI were collected from a number of homes to evaluate the relative abundance of the two components.

In addition, the amphiboles in ZAI were compared to standard reference amphibole minerals from Jamestown, California, and Shinness, Scotland. The amphibole in the Jamestown material is an asbestos tremolite that has been shown to be a highly potent carcinogen in cell studies and animal studies. The physical and chemical properties of this material have also been extensively studied, including the size and shape distribution of the asbestos fibers produced from the material. The amphibole in the Shinness material is a non-asbestos, prismatic amphibole that is typically used as a non-asbestos control in cellular and animal studies. The material has no natural fibers, and forms elongated cleavage fragments when crushed.

The percentage of fine amphibole in ZAI is discussed in the following section and compared with Grace historical data. That discussion is followed by a comparison of ZAI with the reference amphibole minerals from Jamestown and Shinness.

A. Percentage of Fine Amphibole Particles in ZAI

Several homes were tested to determine the asbestos content of vermiculite attic insulation as part of litigation (Barbanti). The survey team selected random locations in the attic of each home from which to collect the samples. The sampler separated ZAI into three layers of material in the attic (top, middle, and bottom). Separation into three layers was intended to address particle settling due to installation and subsequent vibration or other actions. The two size fractions were chosen because, as both experts in Barbanti agreed, only the asbestos content in particles that can become airborne (< 0.5 mm) is of relevance to disturbances potentially caused by homeowners and contractors.

Upon receipt at the laboratory, each layer was separated using a screen into a coarse, non-respirable fraction (larger than 0.5 mm) and into a finer fraction (smaller than 0.5 mm) that contained the respirable particles in the sample. The fine fraction (< 0.5 mm) was examined in the scanning electron microscope (SEM) using a draft ISO analytical procedure²⁹ (essentially an SEM version of NIOSH 7402). Table 3 is a summary of the bulk data from these homes.

The size data from all of these samples shows the particles to be primarily coarse non-respirable material (generally more than 96% by weight is coarser – or thicker – than 0.5 mm).

²⁹ A. Baujon (1989). "Ambient atmosphere – Direct Determination of asbestos fibres and other inorganic particles – Scanning electron microscopy procedure", ISO/TC 146/SC 3/WG1 N26, September 7, 1989. The draft method was recently issued as an official ISO method – ISO 14966:2002(E), First edition 2002 – 11 – 15.

Thus, the fine fraction (< 0.5 mm) which contains any asbestos that could become airborne is a very small portion of the total. In fact, expressed as a portion of the total sample, the overall asbestos content of this fraction was 0.01% or less. Analysis of the layers showed no systematic difference in the asbestos content. Thus there is no evidence of segregation of asbestos by depth in the vermiculite.

B. Historical Data

In the 1970's and 80's, W. R. Grace conducted tests to determine the asbestos content of ZAI. Much of this testing was performed using either x-ray powder diffraction (which cannot distinguish asbestos from cleavage fragments) or by PLM (with no exclusion for cleavage fragments). Generally, these results show the attic insulation (Libby grades 1, 2, and 3) to contain less than 1% Libby Amphiboles in the expanded product. These values are generally comparable to the total amphibole content observed in the attic samples by the experts in Barbanti.

C. Amphiboles in the Coarse Fraction of ZAI

About 200 pounds of Zonolite Attic Insulation were collected from one attic. The vermiculite was separated from the amphibole and other gangue minerals using a water separation process. About 20 pounds of material were placed in a large container filled with water to a depth of about three feet. The exfoliated vermiculite floated to the surface and the remaining minerals sank to the bottom. The vermiculite was removed from the surface and the water filtered to recover the heavy portion. The filtrate was then processed in a liquid of density 2.9 to separate the amphiboles from the lighter minerals using conventional heavy liquid separation procedures. The sink fraction from the heavy liquid separation was extracted and

dispersed under a stereo optical microscope for examination of the amphiboles. The typical dimensions of the amphiboles extracted were several millimeters in length and width. They occur as either equant or elongated particles (see Figure 4). They are far too large to be respirable particles.

Claimants' experts allege the amphibole particles found in ZAI³⁰ are highly friable and readily pulverize into respirable fibers, i.e., they are indistinguishable from asbestos. Although Claimants' experts cite W. R. Grace's literature in support of their position, the Grace documents actually were referring to the vermiculite, not the amphibole minerals. In any event, Claimants' experts' assertions were evaluated using a mallet and chisel to break one of the equant particles. As can be seen in Figure 5a, the particle pulverized into a number of pieces, all larger than respirable size, and none with the characteristics of asbestos, namely high aspect ratio, curved fibers and splayed ends.

The large particles from the ZAI were compared to fibers in a bundle of asbestos from Jamestown, California (see Figure 5b) that was teased open with a needle. The comparison illustrates two of the well-known mineralogical differences between asbestos and non-asbestos amphiboles: (1) the asbestos amphiboles are comprised of fine fibers with extraordinarily high aspect ratios; and (2) the asbestos fibers are readily separated. In contrast, the amphiboles in ZAI broke into fragments with low aspect ratios characteristic of cleavage fragments.

As discussed earlier, the three primary distinctions between asbestos and non-asbestos amphiboles are: (1) the diameter of the fundamental structure; (2) the adhesion properties of the

particles – asbestos fibers are loosely cemented together while the non-asbestos amphiboles are bound together by crystallographic forces; and (3) the length-to-diameter ratio of the particles. In addition, the non-asbestos amphiboles have perfect cleavage planes which cause them to preferentially break along certain directions, a property not observed in the separation of asbestos fibrils. These fractured surfaces are believed to have fundamentally different properties and biological behavior than the surfaces of the asbestos fibrils that were naturally formed. To achieve a very fine diameter particle (<0.3 to 0.5 micrometer), a cleavage fragment has to be repeatedly broken, which requires far more energy to accomplish than the simple separation that produces very fine asbestos fibrils.

RJ Lee Group undertook a comparison of ZAI amphiboles to tremolite asbestos from Jamestown, California; and the non-asbestos tremolite from Shinness, Scotland. Pieces of each of these amphiboles, both equant and elongated were mounted in epoxy. Polished cross-sections of the particles were then made in a direction perpendicular to the c-axis or fiber axis.

As seen in Figure 6a, the asbestos amphibole (Jamestown) has an open structure, comprised of ultrafine diameter crystals, predominantly less than 0.3 - 0.5 micrometers in diameter. From these micrographs, it is apparent why the bundles can be readily separated into long, flexible fibrils. In contrast, the Shinness sample (Figure 6b) is formed from coarse crystals (>10 micrometers) that are tightly bound to adjacent grains. Incipient microcracking along the 110 cleavage planes is visible. The ZAI amphiboles (Figures 6c, d) have a finer crystal structure than the Shinness amphibole, but are much coarser than the Jamestown material. The crystals

Continued from previous page

³⁰ R. Hatfield and W. Longo (2003). "Zonolite Attic Insulation Report", Materials Analytical Services, Inc., Continued on following page

are generally bound tightly together. Incipient cracking along the 110 cleavage planes is apparent (Figure 6d).

The vast majority of the amphibole in the ZAI are coarse, non-respirable particles containing prismatic and acicular amphibole grains. The similarity of the amphiboles in the polished cross sections to the Shinness material— **never shown to have any biological effects** — and their difference from the Jamestown fibers — **a fiber population that has been repeatedly shown to be highly potent** —is obvious. These particles have survived the extraction from the ore, processing at the mine, thermal expansion at the expansion plant, shipping to the home, installation, removal, and the physical separation processes required to view them. There is no possibility that any ordinary disturbance will cause them to fracture or release respirable airborne asbestos fibers.

Thus only the fine portion of the amphibole particles in ZAI has even the potential to become airborne. As reviewed in the following section, several investigators have conducted simulations to evaluate the significance of this potential.

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March 21, 2003, p 18 – 20.

VI. Review and Analysis of Air Samples

Claimants' experts and Lees and Mlynarek³¹ (on behalf of W. R. Grace) have studied the airborne concentrations produced when disturbing ZAI under various scenarios. The studies all involve simulations of disturbances of ZAI that are postulated to represent something a homeowner or contractor might do. In all the simulations air samples were collected, and Claimants' experts also collected surface dust samples. The air samples were analyzed by PCM and TEM, using direct preparation procedures, and the surface dust samples were prepared using the indirect methodology.

Claimants' experts assert that the amphibole particles that become airborne during the disturbance of ZAI are indistinguishable from asbestos fibers. We disagree.

A. Airborne Amphibole Fibers Generated by Disturbing ZAI are Largely Non-asbestos Cleavage Fragments

Examination of the particle size data clearly demonstrates that when Claimants' experts used the direct preparation technique, the size distribution of the amphibole particles observed was substantially the same as the size distribution observed in the Lees and Mlynarek study.

Similarly, the total amphibole concentrations obtained in the TEM analyses were generally in the same range for the different scenarios, whether performed by Claimants' experts or Lees and Mlynarek. Thus the central question is whether the amphibole particles meeting the counting criteria were in fact asbestos fibers or cleavage fragments.

³¹ P. Lees and S. Mlynarek (2003). "Report: Assessment of Potential Asbestos Exposure Resulting from Disturbance of Zonolite™ Vermiculite Attic Insulation", January 9, 2003

Claimants' experts draw no distinction between the different amphibole forms. In fact, Hatfield has been quoted in the press saying that any amphibole particle with a 3:1 aspect ratio is asbestos³². Longo and Ewing claim simply to be following the "rules" outlined in regulatory methods. Interestingly, their own data provides support for the distinctions they ignore and that are widely recognized by other experts.

As mentioned earlier, it is well recognized that a distinguishing characteristic of asbestos is that the asbestos fibrils have a very narrow range of diameters while cleavage fragment widths are not so limited³³. As a result, as fiber length increases, the width of the fibers should remain constant if they are derived from an asbestos population. As seen in Figure 7 for both MAS and RJ Lee Group data, the length of the fibers found in the air samples increases as the width increases—**indicating they are not from an asbestos population.**

Conversely, if the airborne particle population is derived from a population of cleavage fragments, as the length increases it is expected that the width will increase because the particles must be formed by breaking larger fragments into smaller ones. This implies that the aspect ratio should be nearly constant as a function of width. As also can be seen in Figure 7, for both MAS and RJLG data, the aspect ratio is nearly constant — **indicating the fibers are from a population of cleavage fragments.**

³² Warwick Advertiser (2000). "Quarry quandary: Residents, expert question laboratory's independence", newspaper article, September 22, 2000.

³³ A. Wylie, K. Bailey, J. Kelse, and R. Lee (1993). "The Importance of Width in Asbestos Fiber Carcinogenicity and Its Implications for Public Policy", American Industrial Hygiene Association Journal, 54, p. 239 – 254.
G. Burdett (1998). "Final Report for R42:70: Quantitative measurement of asbestos and other fibres in bulk materials", Health & Safety Laboratory, Report IR/L/MF/98/02, August, 1998.

Thus size and shape characteristics of the airborne fibers define the population as non-asbestos. The proof goes further, however. Comparison of the MAS width distribution (excluding bundles) with the distributions reported by Addison³⁴ demonstrates that the width distribution of the amphibole particles reported by Claimants' experts is substantially identical to that of the Shinness fibers – **a fiber population never shown to have any biological effects** – and much thicker than Jamestown fibers – **a fiber population that has been repeatedly shown to be highly potent**. See Figure 8.

The difference between the Jamestown fibers and the ZAI amphibole particles is obvious like the difference in the polished cross sections. The similarity between diameter distributions of the Shinness and ZAI fibers is also apparent. Equally important is the observation that less than 10 percent of the ZAI fibers have diameters below 0.3 micrometers, the diameter recognized by the most recent EPA-sponsored risk assessment as the diameter below which long fibers become highly toxic. Moreover, more than 90% of the ZAI particles have a diameter larger than 0.5 micrometers, the upper limit often reported for asbestos fiber diameter.

Thus, the analysis of the mineral populations observed in the simulations conducted by Claimants and by W. R. Grace leads to the inescapable conclusion that 90 percent or more of the mineral particles released when disturbing ZAI are non-asbestos cleavage fragments that should be excluded from the estimates of asbestos fiber concentration.

³⁴ J. Davis, J. Addison, C. McIntosh, B. Miller, and K. Niven (1991). "Variations in the carcinogenicity of tremolite dust samples of differing morphology", Proceedings of the Collegium Ramazzini Symposium, New York, 1990. Annals of the New York Academy of Sciences; 643; p. 473 – 490.

B. Ambient Air Tests

Air samples were collected in homes that contained vermiculite attic insulation. These air samples were analyzed using EPA's AHERA protocol (40 CFR, Part 763, Appendix A to Subpart E). The data are summarized by residence address in Table 4. In the 12 houses tested, all of the indoor samples, with one exception, were negative for airborne amphibole asbestos. In one sample, a single fiber longer than 5 μm was observed (for a concentration of 0.0022 f/cc). These results indicate the air inside homes with ZAI is not contaminated with asbestos fibers.

C. Simulations

Simulations have been conducted by several groups to determine the airborne concentration of asbestos during attic cleaning, vermiculite removal, or other disturbance of the vermiculite attic insulation.

1. Lees and Mlynarek

The most extensive and most completely documented simulations were conducted by Lees and Mlynarek. RJ Lee Group assisted with the sample collection and performed the laboratory analysis. A home near Albany, New York contained several inches of ZAI on top of existing batt-type fiberglass insulation. A number of tests were performed at the home, grouped into the following categories: (1) cleaning and storage; (2) small scale removal; (3) large scale removal; and (4) renovations. (Complete details of the tests are reported in the Lees and Mlynarek report³⁵.)

³⁵ P. Lees and S. Mlynarek (2003). "Report: Assessment of Potential Asbestos Exposure Resulting from Disturbance of Zonolite™ Vermiculite Attic Insulation", January 9, 2003.

Air samples were collected during all simulations. Personal air samples were collected on workers, helpers, and at least two bystanders. Area air samples were collected in the attic during the tests and also inside and outside the house away from the work area. All of the samples were analyzed by both PCM (NIOSH 7400) and TEM (NIOSH 7402). The TEM procedure was slightly modified to fully identify and enumerate the cleavage fragments (non-asbestos). Each test was conducted until the task was completed (approximately 45 minutes for cleaning, 10 – 20 minutes for removal, and 180 minutes for the renovation). In general, these were short duration tasks. The personal data are summarized in Table 5.

The average asbestos concentrations during the four activities (asbestos task concentration) were 0.003 f/cc (cleaning), 0.118 f/cc (small scale removal), 0.195 f/cc (large scale removal) and 0.024 f/cc (fan installation). When reported as a TWA, the asbestos concentrations average 0.002 f/cc, 0.004 f/cc, 0.010 f/cc, and 0.010 f/cc, respectively, all of which are significantly below the OSHA permissible exposure limit.

These data can also be used to show the extent to which PCM overestimates asbestos concentrations in a dusty mixed-fiber environment such as an attic. For workers, PCM concentrations overestimated the amphibole concentrations (PCME cleavage fragments and asbestos fibers) by a factor of 4-fold. When compared to PCME asbestos fiber concentrations, the worker concentrations were overestimated by PCM by a factor of at least 24-fold. Finally, the data shows that including the PCME cleavage fragments in the workers concentrations overestimates the actual concentration by at least 10-fold.

Lees and Mlynarek also collected air samples within the home before each test and during the tests. These locations were in the downstairs living room, the master bedroom, and

the hall closet leading to the attic entrance. None of the living space air samples were found to have any statistically significant concentration of asbestos. Only one of these living space samples (out of 62 analyses) collected during the simulation detected any asbestos fibers (0.006 f/cc).

2. EPA Phase 2 Data

As part of its investigations in Libby, MT, the U.S. Environmental Protection Agency (EPA) performed several simulations in homes containing ZAI as part of its Phase 2 investigation. "Scenario 3" samples were those collected during purported home repair simulations. Samples identified as Scenario 3 samples were evaluated to determine the PCM and TEM concentrations. Because the contract laboratories did not perform NIOSH 7402 analyses, the TEM data were evaluated to determine the PCME (PCM equivalent – 5µm and longer, 0.25 µm and wide, and at least 3:1 aspect ratio) concentrations. In keeping with proper risk analyses procedures, only samples prepared using a direct preparation procedure were evaluated. The TEM fiber data were further evaluated to determine the true asbestos concentration. This additional evaluation was performed by a review of the drawings of the observed fibers and by using a discriminating algorithm similar to that developed by Wylie³⁶.

The average concentrations for the scenario data are shown in Table 6, listed under "Renovations". All samples were of short duration with an average duration of 60 - 180 minutes. The PCM concentration averaged 0.34 f/cc, while the PCME amphibole concentration averaged

³⁶ A. Wylie (1988). "Discriminating Amphibole Cleavage Fragments from Asbestos: Rationale and Methodology", Proceedings of the VIIth International Pneumoconiosis Conference, Part II. Pittsburgh, PA, August 23 – 26, 1988. NIOSH, U.S. Department of Health and Human Services, DHHS (NIOSH) Publication No. 90-108 Part II, p. 1065 – 1069.

0.128 f/cc, and the PCME asbestos concentration averaged 0.009 f/cc. These concentrations, which are not 8-hour TWA concentrations, but are task concentrations only, are consistent with those reported by Lees and Mlynarek.

3. Versar

A third simulation was performed for EPA by Versar³⁷. This study, only available as a draft report, discusses airborne concentrations observed during various activities (similar to Lees and Mlynarek) involving expanded vermiculite. The data from these tests are summarized in Table 12 of the Versar report and are included in Table 6 of this report. The raw data from the testing were not available for review; the reported TEM concentrations are assumed to represent a combination of cleavage fragments and asbestos fibers.

During the "Small Scale Removal" (see Table 6), Versar found airborne fiber concentrations by PCM in ranges consistent with those reported by Lees and Mlynarek. Testing by Versar that could be classified as either "Large Scale Removal" or "Renovations" found concentrations consistent with Lees and Mlynarek for both PCM and TEM amphibole fibers.

VII. Critique of Claimants' Experts' Simulations

Review of the simulations relied upon by Claimants' experts revealed numerous deficiencies. The work plans and simulations were superficially similar to those of other investigators, but lacked critical elements of quality control, failed to adequately describe or characterize the environments, and used inappropriate methodologies. For example, personal air

³⁷ Versar (2002). "Preliminary Draft: Asbestos Exposure Assessment for Vermiculite Attic Insulation", Versar, Inc. Springfield, VA, June 28, 2002.

samples were collected and analyzed by PCM (item 666) and TEM (EPA Level II, item 664). RJ Lee Group attempted to independently calculate the concentrations for the samples, but was precluded from doing so due to missing data (such as missing grid opening dimensions for samples W-45-3 and H-45-1).

A more detailed critique of the simulations and measurements are presented in the following sections.

A. Claimants' Experts' Simulations

Two simulations have been performed by Claimants' experts – MAS and Ewing, et al. MAS performed a cleaning simulation at a home located in Silver Spring, MD (items 664 – 666) in March, 2003. No detailed description of the activities is available, so it is unclear what activities actually occurred during the "cleaning". The test does not describe whether the area was isolated from the rest of the house during the test by plastic barriers or whether airflow through the attic was augmented or reduced artificially.

Because of the missing information (experimental plan, actual operations, and analytical data) and the inclusion of cleavage fragments in the reported TEM concentrations, the studies must be considered as unreliable.

Ewing, et al³⁸, conducted several simulations in two homes in Spokane, WA in November, 2002. One cleaning test, one renovation, and three large-scale removal tests were conducted. Prior to conducting the tests, Ewing, et al artificially isolated the test rooms from the

³⁸ W. Ewing, T. Dawson, R. Hatfield, W. Longo, P. Liss, S. Hays, R. Gobbell, and P. Cappell (2003). Zonolite Insulation Exposure Studies, March 15, 2003.

remainder of the house by using plastic sheeting. This has the effect of blocking any natural convective air currents from moving through the attic. This artificial environment has the effect of inflating the apparent airborne concentrations.

One additional significant problem with the Ewing study is the lack of observed chrysotile fibers in the air samples from the ceiling penetration test. In this test, a hole was sawed into the ceiling by the worker using a compass saw. As identified by MAS (sample M29780-007a), the ceiling plaster contained 7% chrysotile by volume. However, no chrysotile was reported in any air sample collected during the test and analyzed by TEM. MAS has claimed in the past³⁹ that simply abrading asbestos-containing plaster generates airborne asbestos concentrations, which they have characterized as very high. Failure to find even one chrysotile fiber makes the credibility of the analysis a significant concern.

1. Conversion to PCME/Impact of Counting Cleavage Fragments

Many of the TEM structures that are reported in the Claimant simulations are shorter than 5 μm . As discussed in the literature and at a recent expert panel hearing⁴⁰, fibers shorter than 5 μm pose no excess risk for the causation of either lung cancer or mesothelioma. As such, exposure study data should be restricted to those fibers that have been shown to be related to lung cancer and mesothelioma (PCME asbestos fibers) as incorporated into the EPA and OSHA risk models. The exposure studies summarized in Tables 4-5 have had the TEM data evaluated to determine the PCME fiber concentration, excluding the fibers < 5 microns in length. These

³⁹ W. Longo and R. Hatfield (1999). *Kelly-Moore: Mixing, Applying, Sanding & Cleanup of Asbestos Containing Finishing Compound – Work Practice Study*, Materials Analytical Services, Inc.

fibers are the only sizes that relate to the risk factors determined for EPA's IRIS and used in OSHA's risk model.

These PCME particles were then further evaluated to determine if they were asbestos fibers or cleavage fragments using the same algorithm as was used for the EPA Phase 2 data. More than half of the PCME-sized particles in the Longo studies were identified as cleavage fragments. Ninety-three percent of the PCME-sized particles in the Ewing study were identified as cleavage fragments. These percentages are consistent with other studies and inflate reported asbestos concentrations.

2. Impact of Containment/No Ventilation on Air Sample Results

The reports issued by Claimants' experts do not specify the airflow in the attics that were tested. Most attics have gable vents or a ridge vent that forms a natural convective current from the house through the attic and to the outdoors. This current of air, as measured by Lees and Mlynarek, acts to carry any airborne particulate out of the attic and away from the worker/homeowner. When the rooms are artificially separated from the rest of the house, such as in Ewing, et al., this air current is disrupted, causing airborne particulate to artificially concentrate in the attic air. This artificially inflates the resulting concentrations.

3. TWA Calculations

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⁴⁰ ATSDR (2002). "Expert Panel on the Health Effects of Asbestos and Synthetic Vitreous Fibers (SVF): The Influence of Fiber Length", Panel meeting, New York, NY, October 29 – 30, 2002, meeting handout.

Ewing incorrectly refers to his reported average airborne concentrations measured during the simulations as "TWA" concentrations. In fact they are task concentrations, reflecting only the airborne concentrations during the performance of the simulation. OSHA has established an 8-hour standard to which an employee may be exposed over his/her working lifetime without restriction. Comparisons of actual exposures with this standard are adjusted to their eight-hour time weighted average. It is generally accepted within the industrial hygiene and regulatory community that the acronym "TWA" refers to the OSHA eight time-weighted average. To use it as a comparison to alleged asbestos exposure is misleading.

RJ Lee Group independently recalculated the task concentrations and included them in Table 6. After accounting for the cleavage fragments, the Ewing, et al task concentrations are generally consistent with those of Lees and Mlynarek.

B. Pinchin

Claimants' experts cite a demolition study performed by Pinchin Environmental (item 611 of Claimants' reliance documents) at a Canadian military base in Shilo, Manitoba. Building E12 was a one-story wood frame building with drywall ceilings and vermiculite attic insulation. Two simulations were performed: 1) a gross demolition of the ceiling drywall and subsequent dispersement of insulation; and 2) an abatement-style insulation removal. Air samples were collected and submitted for analysis using both PCM (NIOSH 7400) and TEM (NIOSH 7402).

Many of the PCM samples (Appendix II of the Pinchin report) were overloaded with dust and could not be analyzed. Those that could be analyzed show concentrations ranging from nondetect to as high as 18 f/cc (sample 77955).

Eight of the samples from the gross demolition testing were analyzed by TEM (Appendix III of the report). Though the report states the samples were analyzed using NIOSH 7402, numerous deviations from the protocol occurred. Each sample was prepared for TEM analysis using an indirect preparation procedure (as indicated by "Fraction Re-filtered:" on the data tables). On each sample, 10 grid openings were analyzed instead of the mandated 40. In addition to the fibers that must be counted by NIOSH 7402 (longer than 5 μm and wider than 0.25 μm), fibers shorter than 5 μm , as well as fibers longer than 5 μm but thinner than 0.25 μm were separately counted (page 5 of the report). Because of these deviations from the protocol, the data cannot be used for exposure assessment and must be considered as unreliable.

C. Grace Historical Testing

W. R. Grace conducted various attic simulations related to possible fiber exposure during installation of ZAI. Due to the artificial nature of the simulated attic testing location, the reported data can only be considered as an indication of the airborne fibers of all types. As noted by Yang⁴¹, the principal method of analyzing these samples was an optical technique consistent with NIOSH 7400 (PCM). No attempt was made to perform a differential count to exclude nonasbestos fibers. Much of this data shows estimated airborne concentrations averaging 1 to 2 f/cc during the simulated attic tests. These data are consistent with those generated by Versar (and discussed above).

⁴¹ Depositions of Julie C. Yang, Ph.D., in United States of America v. W. R. Grace & Co., et al., Civ. No. 01-72-M-DVM at pp. 156-158, 164-165 (Aug. 21, 2002), and In Re W. R. Grace & Co., et al., No. 01-01139 JFK at pp. 83-84 (Feb. 20, 2003).

As documented in both Claimants' and the Lees and Mlynarek study, only a small portion of PCM-sized fibers are asbestos fibers. The data shown in Table 5 indicate that the average reduction of worker task concentration, obtained by analyzing the samples for PCME amphibole particles instead of PCM fibers, is nearly 4-fold. When the PCME amphiboles are further discriminated to include just asbestos fibers (not cleavage fragments), there is more than a 24-fold reduction in concentration (PCM to PCME asbestos), on average. Thus, only about 6% of the PCM fibers are PCME asbestos.

This observation that not all fibers in the air are asbestos fibers is supported by a study performed by Wylie and Watson⁴². In their study, samples of vermiculite were agitated in a glove box to generate a known source of airborne particulate. The airborne particles were sampled and analyzed using PCM (7400) and TEM (7402). Wylie and Watson concluded:

"The source of elongated particles counted by PCM are primarily vermiculite. The majority of the elongated vermiculite particles were plates with some scrolled tubes. An average of < 1.5% of elongated particles counted by PCM could be classified as asbestos."

This estimate of approximately 1.5% of the PCM fibers as asbestos compares favorably with the Lees and Mlynarek simulation estimate of 6%. Both values show that most of what is observed in the PCM is not asbestos, indicating the PCM procedure is not adequate for evaluating possible airborne vermiculite particles.

⁴² A. Wylie and M. Watson (1994). "Airborne Fibers Generated From Vermiculite", June 20, 1994.

D. Dust Samples

Numerous samples of surface dust were collected by Claimants' experts in houses purportedly containing ZAI. Claimants' experts argue that their measurements are indicators of past airborne concentrations and indicators of future concentrations.

1. Surface Dust Concentrations are Not Predictors of Past or Future Exposures

Proponents of surface dust sampling often claim that the concentration of asbestos fibers found on a surface is a predictor of potential future airborne concentrations. There is no scientific basis for this claim. Studies have found that, even with surface dust concentrations in the millions of structures per square centimeter, airborne levels are barely measurable.

These proponents ignore the disaggregating effects of the indirect preparation procedure. They also ignore the tendency of asbestos to stick to surfaces, and the effects of moisture and other parameters on the tendency for surface dust to resist becoming entrained by a disturbance.

The potential for re-suspension of the surface dust is described by K-factors (in units of cm^{-1}), the ratio of airborne fiber concentration to the surface fiber concentration. Chatfield and Fowler⁴³ examined surface sampling to determine if there was a relationship between surface dust loadings and airborne concentrations. They concluded that current dust analytical procedures, while practical analytical tools, do not preserve the size distribution of the particles as they existed on the surface. Without the knowledge of the condition of the particles on the

⁴³ D. P. Fowler and E. J. Chatfield (1996). "Surface Sampling for Asbestos Risk Assessment", presented at Inhaled Particles VIII, August 26-30, 1996.

surface, it is impossible to determine k-factors. Chatfield reiterated this conclusion in a later paper⁴⁴ by saying "simple resuspension factor calculations using surface dust measurements ... do not provide a valid scientific basis for prediction" of airborne asbestos concentrations.

Other studies⁴⁵ have reached similar conclusions. Moreover, in a recent Daubert ruling, the federal bankruptcy court found "that dust results do not give an indication of what has been in the air, nor do they demonstrate release potential of asbestos-containing materials ..."46.

2. Particles Found in Dust Samples were Primarily Cleavage Fragments.

In addition to being unreliable indicators of potential future airborne exposures, the dust sample results demonstrate that the vast majority of the particles in the dust are cleavage fragments. Table 6 summarizes the dust data from Claimants' testing and compares those reported results with the data after the TEM fiber sizes were evaluated to determine PCME concentrations. These fibers were then further analyzed to determine if they were asbestiform using the same algorithm as used for the EPA Phase 2 data. The data show there are very few PCME asbestos (risk) fibers in the dust data. As with the air data, 86% of the particles in the PCME size fraction are cleavage fragments and not asbestos.

⁴⁴ E. J. Chatfield (1999). "Correlated Measurements of Airborne Asbestos-Containing Particles and Surface Dust", in *Advances in Environmental Measurement Methods for Asbestos*, M. E. Beard and H. L. Rook, eds, American Society for Testing and Materials, publication STP 1342, p. 378 – 402.

⁴⁵ R. J. Lee, D. R. Van Orden, and I. M. Stewart (1999). "Dust and Airborne Concentrations – Is There a Correlation?", *Advances in Environmental Measurement Methods for Asbestos*, ASTM publication STP 1342.

⁴⁶ R. Newsome (2002). Findings of Fact and Conclusions of Law RE: Motions of the Debtors and Asbestos Property Damage Committee to Exclude Evidence, US Bankruptcy Court for the District of Delaware, In re: Armstrong World Industries, Inc. et al. Case No. 00-04471 (RJN).

VIII. Conclusions

Based on the above discussions, an extensive literature review, discussions with other experts, and personal knowledge of the ZAI mineralogy and analytical techniques, it can be concluded with a reasonable degree of scientific certainty that:

- 1) Phase Contrast Microscopy (PCM) measurements of airborne fiber concentrations in atmospheres where ZAI is being manipulated, handled, or removed by a homeowner significantly overestimate potential "*asbestos*" fiber concentrations. In Claimants' experts' airborne "*asbestos*" fiber counts, the average reduction would be more than three-fold, simply by excluding non-mineral fibers such as hair, cotton, and cellulose.
- 2) *Asbestos* is a commercial term applied to the occurrence (in sufficient quantity to make their extraction and beneficiation economically viable) of *asbestiform* minerals which are minerals with physical and thermal properties of potential commercial significance in applications requiring flexibility, thermal stability or high tensile strength. *Asbestiform* minerals are naturally formed in a fibrous, flexible form with a high aspect ratio known as fibers.
- 3) *Asbestos* minerals have non-asbestos analogs called *cleavage fragments*. When finely divided or crushed, *cleavage fragments* may have a similar appearance to asbestos fibers, but are generally thicker and shorter than asbestos fibers and have other distinguishing characteristics.

4) Regulatory methods are and have been expressly designed to measure the concentrations of asbestos fibers and explicitly cite the "asbestiform varieties of ... [amphibole minerals]" in air, water, or bulk samples, not the concentration of cleavage fragments.

5) Claimants' experts misrepresent the OSHA position by failing to acknowledge that in 1992 OSHA explicitly excluded amphibole *cleavage fragments* from their asbestos regulations.

6) Claimants' experts' TEM analysis is flawed because they included non-asbestiform *cleavage fragments* in their "*asbestos*" count thereby inflating their "*asbestos*" results.

7) Contrary to Claimants' experts' assertions, the majority of the amphiboles in ZAI are neither asbestiform nor respirable.

8) Claimants' estimated concentrations would be reduced by at least ten-fold if the concentration of non-asbestiform *cleavage fragments* in their samples were excluded from their "*asbestos*" count.

9) Exposure measurements made by RJ Lee Group and two groups of Claimants' experts using PCM methodology and adjusted for the quantities of non-mineral fibers and *cleavage fragments*, indicate airborne asbestos concentrations would have been comparable to or below relevant standards.

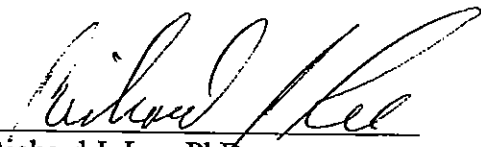
10) Evaluation of Claimants' experts' own surface dust data demonstrates that their use of indirect preparation significantly breaks up the mineral particles in the

samples. The surface dust particles are smaller than the airborne particles thus demonstrating the disaggregating effect of indirect preparation.

11) Neither the ASTM surface dust method(s) nor the indirect preparation technique is generally accepted as a reliable indicator of past or potential future airborne exposures. Results derived from the analysis of samples prepared using an indirect preparation technique cannot be used for risk evaluation.

12) There is no reliable scientific evidence that ZAI is unsafe.

In addition to our own research and studies of asbestos, our opinions and testimony are based on the research and studies of other scientists and governmental bodies. A list of reliance materials on which we may rely to form the basis of our opinions is attached and incorporated by reference; however, we may also rely in whole or in part on the publications as well as opinions, data and materials produced in discovery, or contained in the reports of other experts which the plaintiffs or the defendant designates in this action. We also reserve the right to rely on any scientific articles or studies subsequently presented or published. We have prepared this report in accordance with Rule 26(a) (2) of the Federal Rules of Civil Procedure.


Richard J. Lee, PhD

Figures

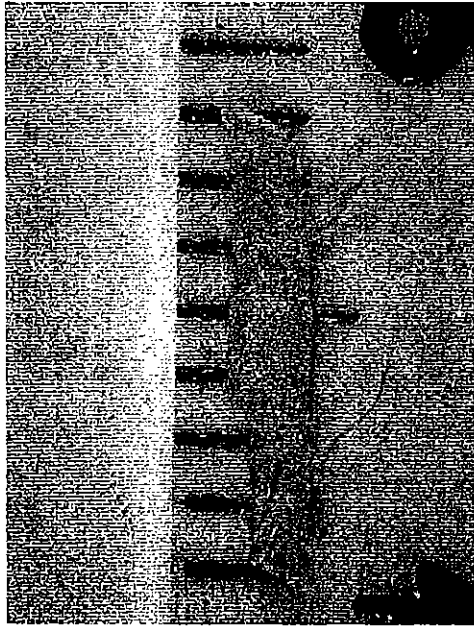


Figure 1a.

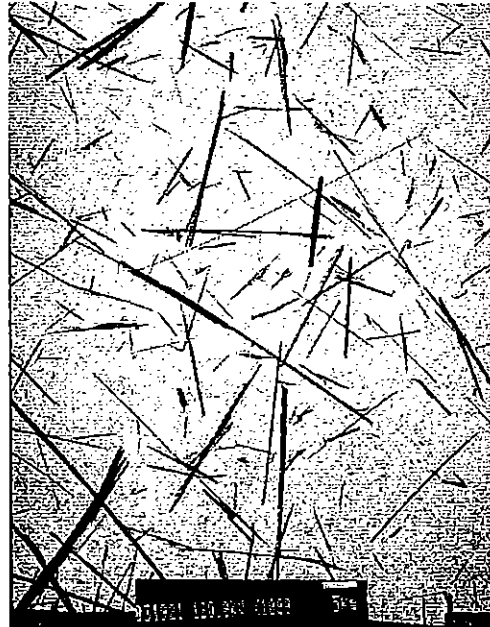


Figure 1b.

Figure 1. A) An optical photomicrograph of a bundle of amphibole asbestos prior to sonication. B) A TEM photomicrograph of the fibrils released from the bundle in figure 1 after 3 minutes of sonication. The average diameter of the fibrils is more than a thousand fold less than the original bundle.

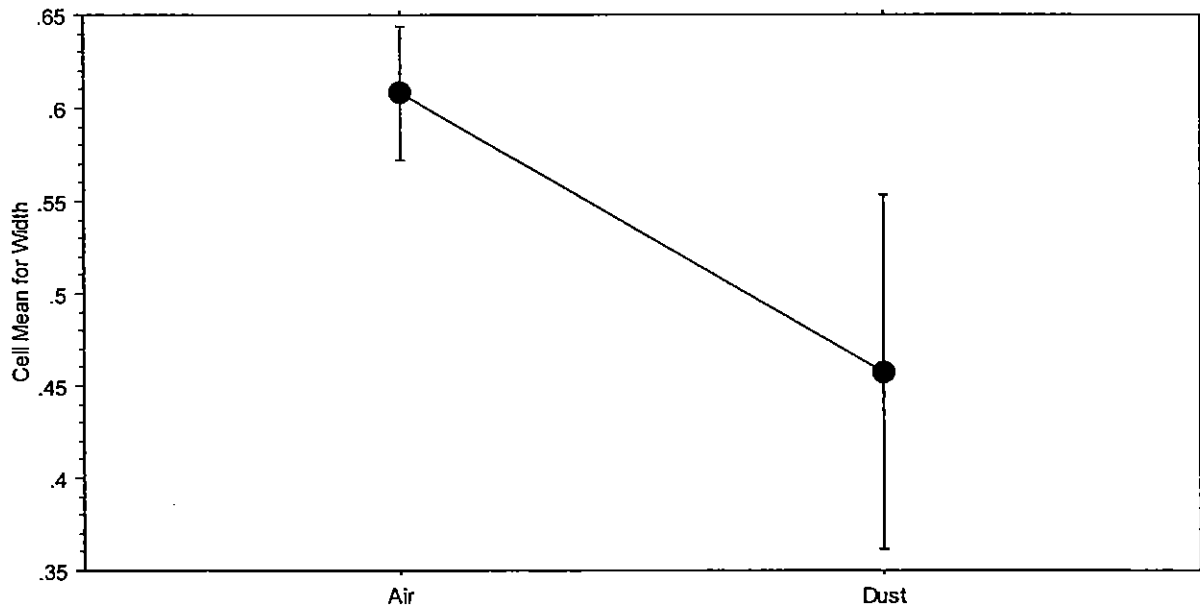


Figure 2. Comparison of the average diameter and 95% confidence interval of the diameters of airborne fibers with the same parameters for fibers found in the dust samples in Claimants' studies. The diameter of the dust particles has been reduced to such an extent that the two distributions are statistically different.

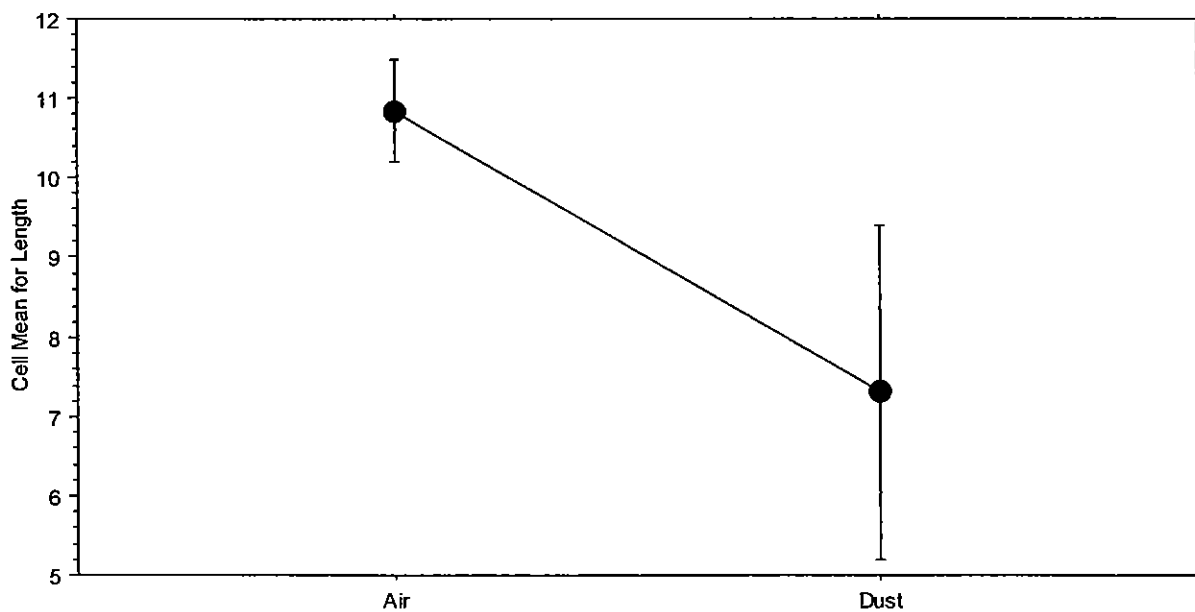


Figure 3. Comparison of the average length and 95% confidence interval of the lengths of airborne fibers with the same parameters for fibers found in the dust samples in Claimants' studies. The length of the dust particles has been reduced to such an extent that the two distributions are statistically different.

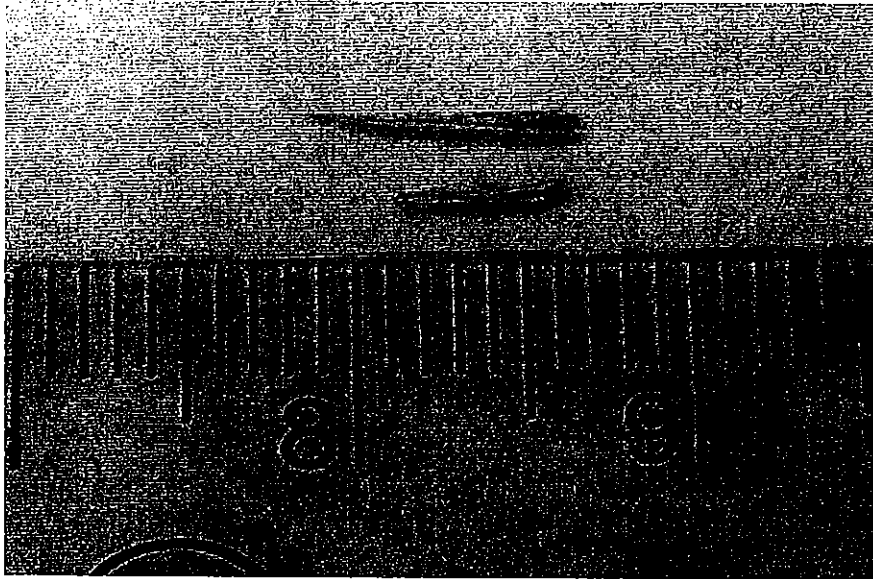


Figure 4a. Typical acicular fragments extracted from ZAI. The particles are typically 5-10 millimeters in length and 1-2 millimeters in diameter.

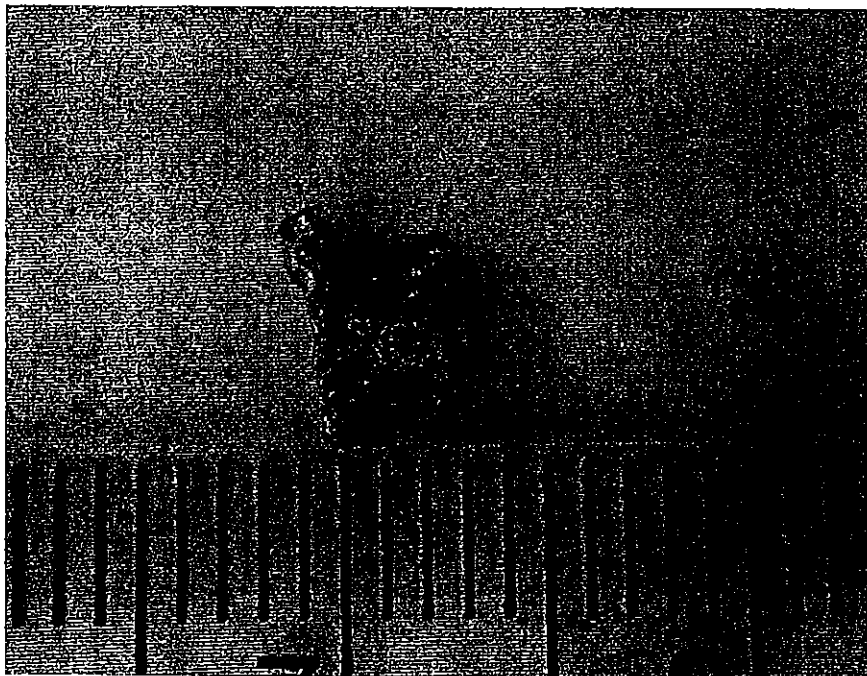


Figure 4b. Typical equant cleavage fragment observed in ZAI. Particles of this type dominate the amphibole fraction of the product.

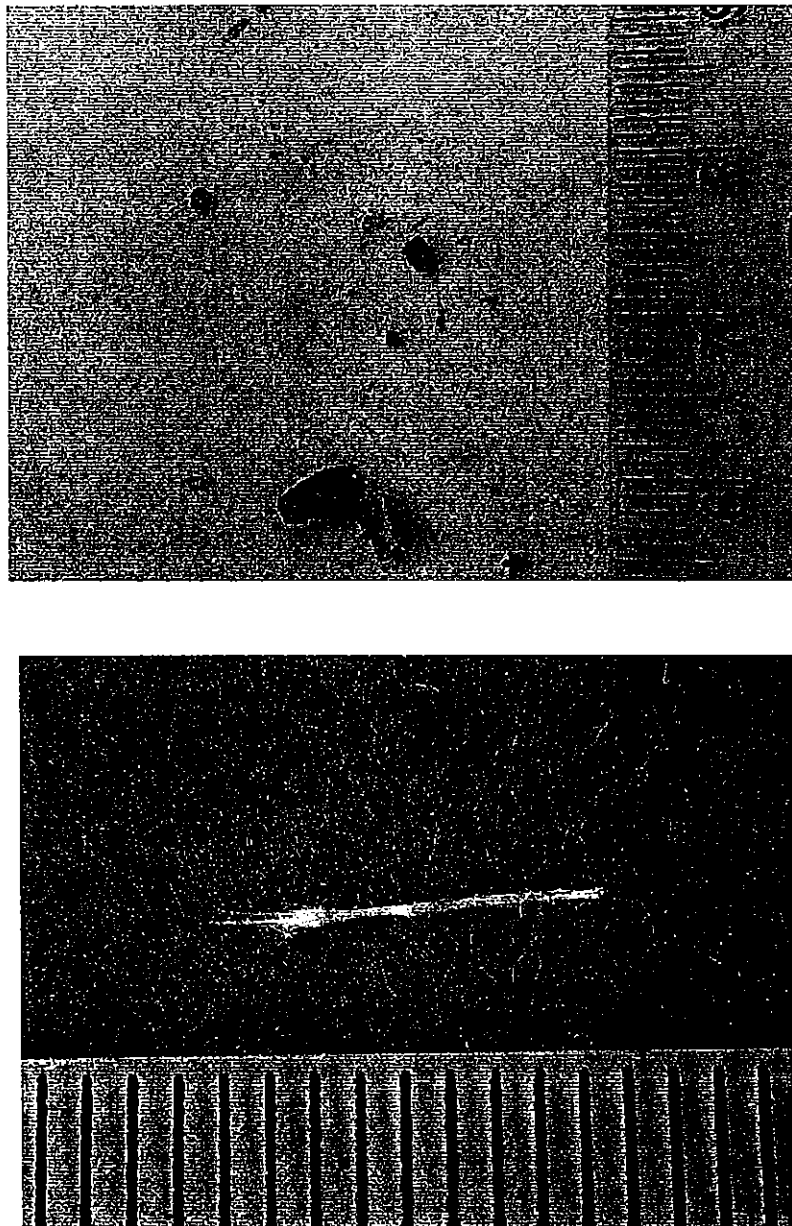


Figure 5. Comparison of broken pieces of an amphibole particle from ZAI (top, particle from Figure 4b) with tremolite asbestos fibers from Jamestown, California (bottom). As seen in the photomicrographs, the aspect ratio and shape of the particles is fundamentally different.

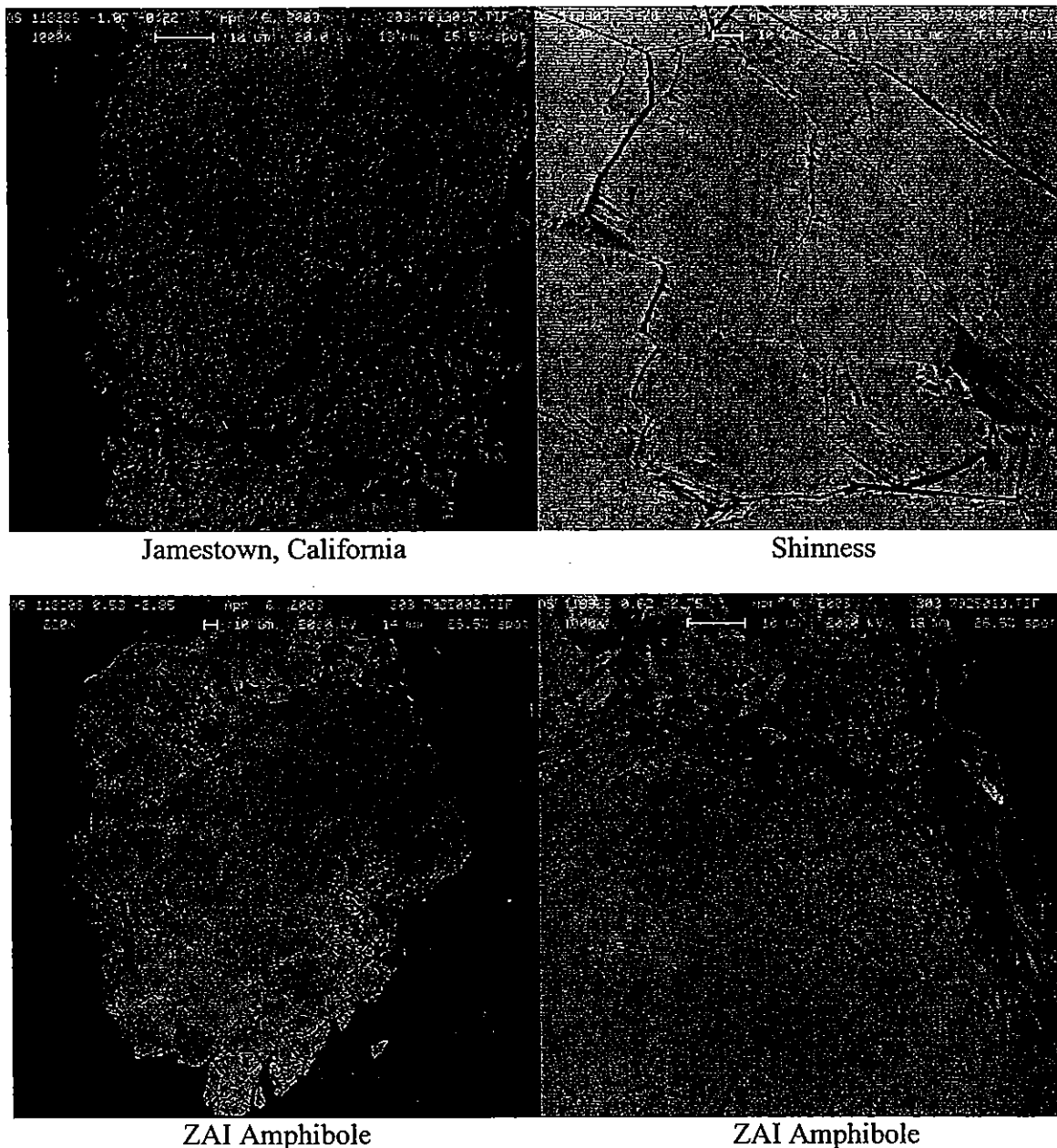
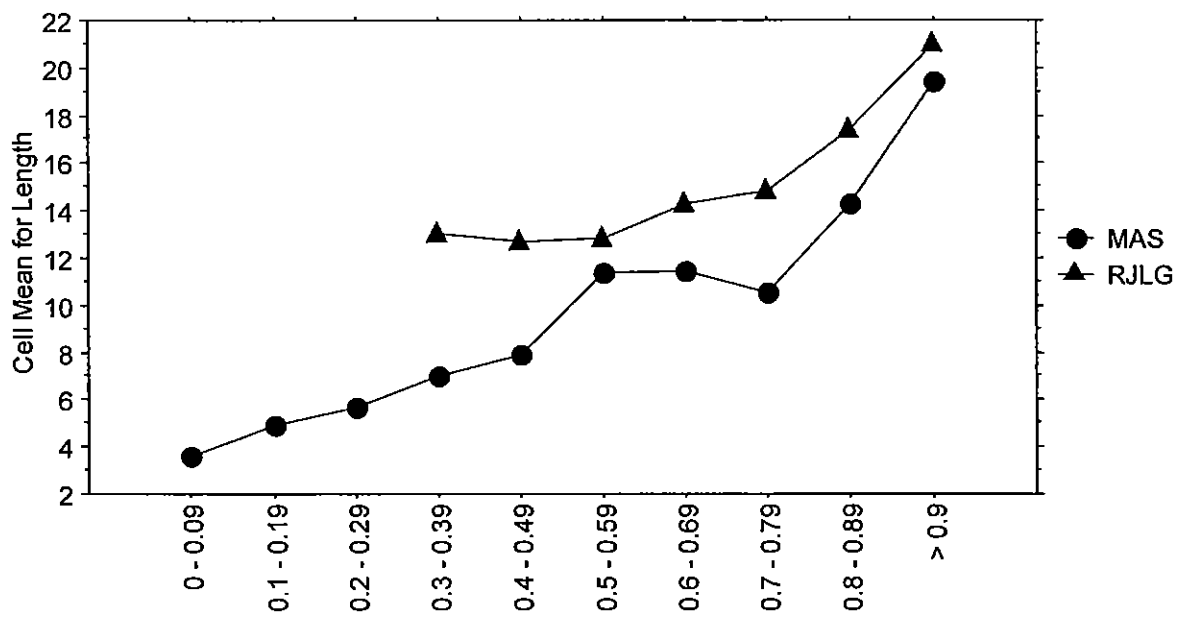
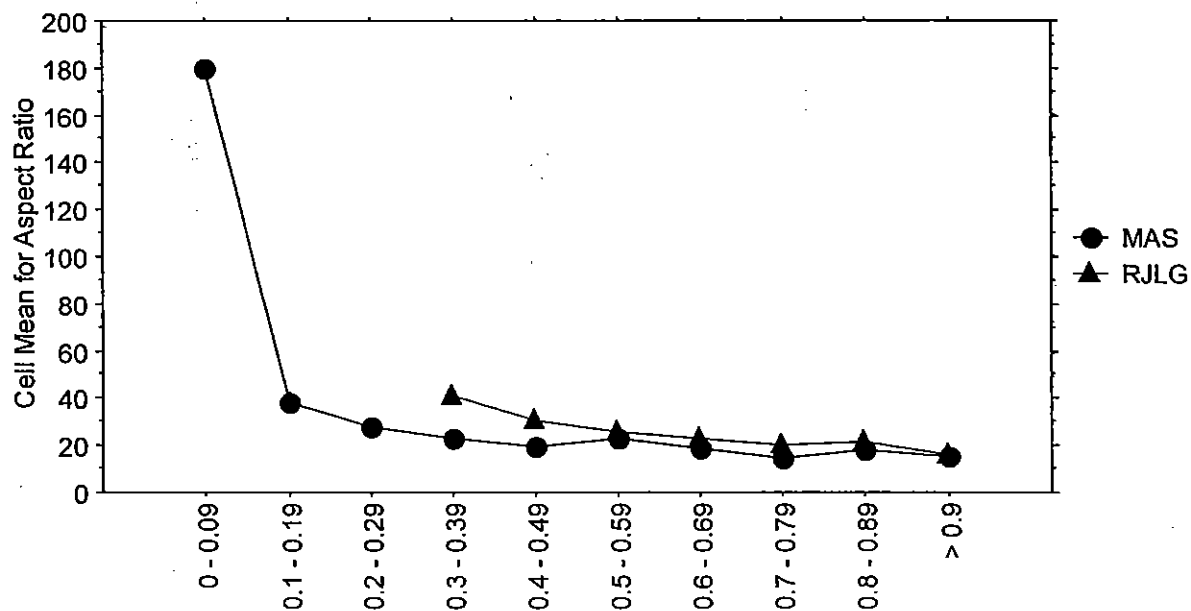


Figure 6. SEM photomicrographs of a polished cross-section of Tremolite asbestos from Jamestown, Shinness, and ZAI. The length of the fibers are perpendicular to the photograph. The typical fibril diameter in the Jamestown tremolite is less than 0.5 micrometer. Note the coarse crystal structure in the Shinness tremolite, well-defined crystal boundaries and smooth features compared to the asbestos tremolite from Jamestown. The ZAI material has characteristics intermediate between the Shinness and Jamestown tremolites. The majority of the material is typical cleavage fragments, bounded by finer crystals generally larger than 1.0 micrometer that exhibit characteristic cleavage faces.



a)



b)

Figure 7. Comparison of the aspect ratio and length distribution obtained by MAS and RJLG in simulations of the disturbance of ZAI. A) Mean aspect ratio for fibers in each width class. B) Mean length for fibers in each width class. The distributions are very similar, and totally different than the distributions obtained for the dust samples prepared by indirect preparation.

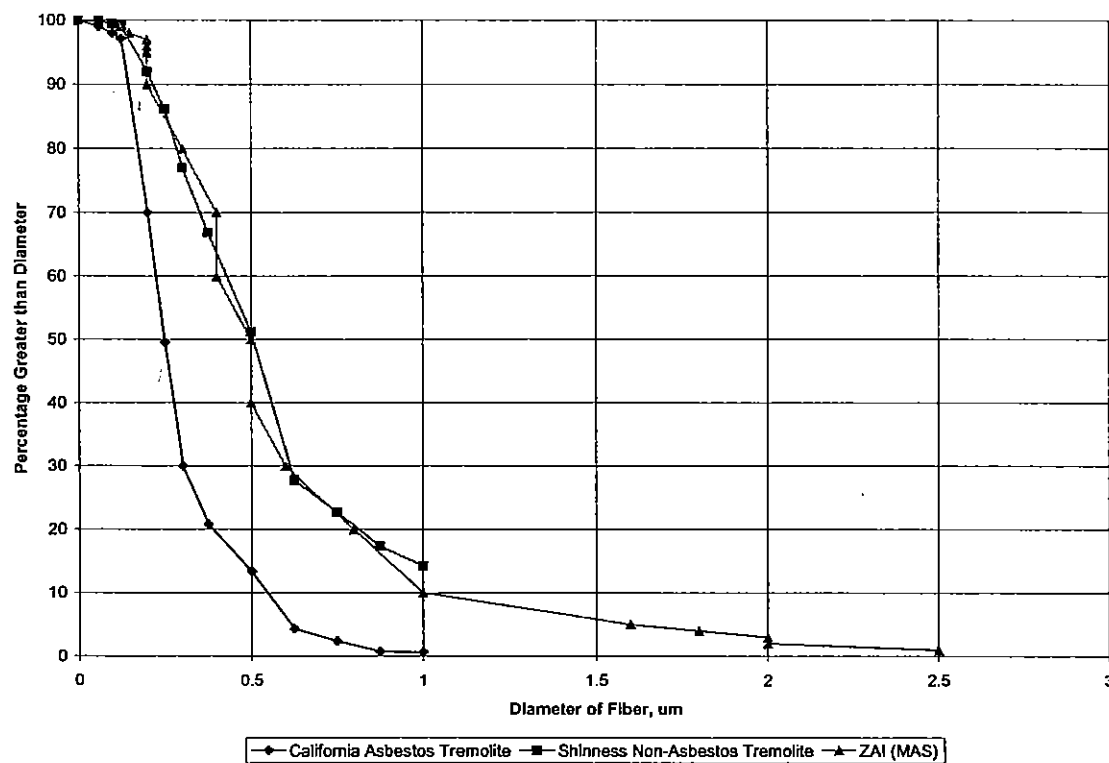


Figure 8. Comparison of the width distribution of amphibole particles observed by MAS with those reported for two reference tremolite standards (Davis, et al.). The amphibole diameter distribution reported for the ZAI amphibole is the same as that of the Shinness tremolite (a mineral shown to have no biological activity in animal injection studies).

Tables

Table 1. Excerpts from Selected References Describing Cleavage Fragments

Reference	Description
Michael E. Beard, EPA Chemist letter to Sally A Sasnett, dated November 3, 1992 ^{T1-1}	Many samples of non-asbestos cleavage fragments have been mistakenly labeled as asbestos. Note that cleavage fragments defined in table 1-1 of the EPA Interim Method (EPA-600/M4-82-020) are not asbestos.
W.J. Campbell, "Identification of Selected Silicate Minerals and their Asbestiform Varieties," NBS Special Publication 506, November 1978 ^{T1-2}	The problem of asbestiform particulates with its environmental and health implications has been compounded by the lack of precision with which the term 'asbestos' has been used. In many instances, non-asbestiform mineral particles have been identified as microscopic fibers of asbestos-related minerals.
W.J. Campbell et al. "Relationship of Mineral Habit to Size Characteristics for Tremolite Cleavage Fragments and Fibers," Bureau of Mines Report of Investigations RI-8367, (1979) ^{T1-3}	Asbestos materials of commercial importance have the following characteristics: Aspect ratios ranging upward to 1000:1 or higher, Very thin fibrils, generally less than 0.5µm in width, Very high flexibility and tensile strength compared to nonasbestos minerals. Parallel fiber growth in veins.
W.J. Campbell et al, "Selected Silicate Minerals and Their Asbestiform Varieties, Mineralogic Definitions and Identification - Characterization," Dept. of Interior, Bureau of Mines, Information Circular 8751, (1977) ^{T1-4}	Cleavage Fragments: A fragment produced by breaking crystals in directions related to the crystal structure and always parallel to possible crystal faces...Amphiboles with prismatic cleavage will produce prismatic cleavage fragments. These fragments resemble fibers. However, because they did not grow as fibers, they cannot have the characteristics of fibers. The EPA Interim Method and the Improved Method define cleavage fragments as particles having aspect ratios less than 10:1 (length to width). Cleavage fragments are not regulated by EPA or OSHA.
Jean Dolensek, "Symposium to Revisit Taconite Tailings," The Minnesota Prospector, January 2003 ^{T1-5}	Asbestiform Mineral - Aspect ratio increases as particles get longer. Mineral Cleavage Fragment - Aspect ratio remains constant and is independent of length.
C-Y Hwang, "Size and Shape of Airborne Asbestos Fibers in Mines and Mills," British Journal of Industrial Medicine, 1983; V40: 273-279 ^{T1-6}	True diameter and true length distributions of airborne fibers in the various stages of fiber processing were non Gaussian. Differences between manufacturing stages were considerably less than between asbestos types.
Ed Ilgren: "Expert Report re WR Grace - Related Attic Insulation Asbestos Litigation - The Biological Relevance of Tremolite Cleavage Fragments: April 10, 2003 ^{T1-7}	Cleavage fragments have fundamentally different properties from asbestos fibers that are biologically relevant. Cleavage fragments lack the strength, durability, flexibility and acid resistance of asbestos. They are therefore unable to persist in the body in a manner similar to asbestos. Scientific evidence demonstrates that cleavage fragments are noncarcinogenic in animals and humans.

Table 1. Excerpts from Selected References Describing Cleavage Fragments, continued.

Reference	Description	
A.M. Langer, R.P. Nolan and J. Addison, "Distinguishing between Amphibole Asbestos Fibers and Elongated Cleavage Fragments of Their Non-Asbestos Analogues" <u>Mechanisms in Fibre Carcinogenesis</u> , Edited by R.C. Brown et al., Plenum Press, New York, 1991 ^{T1-8}	Problems Emerging as the Result of Definitions.	
	PLM Property	
	Optical Level	
	Aspect Ratio	
	TEM Property	
	Sublight level	
MSHA Asbestos Hearing Panel: Public Meeting on Asbestos ^{T1-9} Charlottesville, VA June 20, 2002	Structure	
	SAED	
	P119 Ann Wylie: Cleavage fragments get wider as they get longer whereas for asbestos fibers width is essentially independent of length. Unit fibrils are the basic building block of asbestos; widths are constant and independent. Populations of fibers have very distinctive characteristics. Either half the population is longer than 10µm, or less than 0.5µm, or they have high aspect ratios.	
	P177 Rich Lee: The Libby data clearly illustrate that there is an asbestiform and nonasbestiform population in that airborne population.	
OSHA, "Regulations (Preambles to Final Rules) IV. Mineralogical Considerations." (1992) ^{T1-10}	P6 "Amphibole asbestos populations are characterized by aspect ratios > 20:1." "Asbestos crystallizes in a fluid medium; growth takes place rapidly in one direction." "Because their origin is different, populations of fibers and cleavage fragments of the same mineral are different.	
	P7 "Because of the nature of asbestos, width changes very little as length increases. P9 Due to the straight line fibrillar crystal growth of asbestos, the width of an asbestos fiber is essentially independent of its length. In contrast cleavage fragment populations show increasing width as particle length increases due to normal 3 dimensional crystal growth.	
National Research Council, "Asbestiform Fibers – Nonoccupational Health Risks," 1984 ^{T1-11}	P33 One of the properties shared by high quality fibers of asbestos, whiskers, and glass is their diameter-dependent strength. That is, the strength of the fibers per unit of cross-sectional area increases as the diameter decreases. Thus, the smaller the diameter of the fibers, the greater the strength. P38 The relatively high flexibility of the asbestiform fibers enables them to bend without breaking and may facilitate their passage through the respiratory tract. The exceptional physicochemical durability of asbestiform fibers is one of the basic requirements for their biological effects.	

Table 1. Excerpts from Selected References Describing Cleavage Fragments, continued.

Reference	Description																																																		
R.L. Perkins and B.W. Harvey, "Method for the Determination of Asbestos in Bulk Building Materials," [Improved Method] EPA/600/R-93-116, July 1993 ^{T1-12}	Asbestos: A commercial term applied to the asbestiform varieties of six different minerals... The properties of asbestos that made it commercially useful are its (1) ability to be separated into long, thin, flexible fibers, (2) high tensile strength, (3) low thermal and electrical conductivity, (4) high mechanical and chemical stability, and (5) high heat resistance. These fibers are classified as carcinogens and are regulated by EPA and OSHA.																																																		
E.J.W. Whittaker, "Mineralogy, Chemistry and Crystallography of Amphibole Asbestos," Mineralogical Association of Canada, Short Course in Mineralogical Techniques of Asbestos Determination, Editor R.L. Ledoux, 1979 ^{T1-13}	P30, Fibrous material will approach its theoretical strength if the adhesion across the fibrous cleavage is less than 20-30% of the cohesion of the material... Appropriate nucleation conditions so as to produce many fine fibrils... such as occur in cross-fiber veins permit inherent strength of silicate chain to be manifested in macroscopic properties.																																																		
A.G. Wylie, "The Habit of Asbestiform Amphiboles: Implications for the Analysis of Bulk Samples," from <u>Advances in Environmental Measurement Methods for Asbestos</u> , Michael E. Beard and Harry L. Brooks, Editors, ASTM STP 1342 ^{T1-14}	The Analysis of Bulk Samples, p60. Population of fibers > 5µm w/ 1) aspect ratios >20:1, 2) bundles w/ splayed ends, 3) fiber width < 0.5µm, 4) curved fibers.																																																		
A.G. Wylie, "Modeling Asbestos Populations: A Fractal Approach," Canadian Mineralogist, Vol. 30, p437-446 (1993) ^{T1-15}	Different types of asbestos have different resistances to fragmentation.																																																		
Ann G. Wylie, Robert L. Virta and Estelle Russek, "Characterizing and Discriminating Airborne Amphibole Cleavage Fragments and Amosite Fibers: Implications for NIOSH Method," American Industrial Hygiene Association Journal (46) April 1985 ^{T1-16}	Percentage of Amphibole Cleavage Fragments and Amosite Asbestos Fibers that conform to several dimensional criteria																																																		
	<table><tr><th colspan="4">Percent of Total Particles</th></tr><tr><th>Length and Aspect Ratio</th><th>Width</th><th>Clev Frag %</th><th>Amosite %</th></tr><tr><td rowspan="3">Length≥ 5µm Aspect Ratio ≥ 3</td><td>All widths</td><td>41</td><td>64</td></tr><tr><td>w≥0.25µm</td><td>41</td><td>50</td></tr><tr><td>3µm≥w≥0.25µm</td><td>39</td><td>50</td></tr><tr><td rowspan="3">Length≥ 5µm Aspect Ratio ≥ 10</td><td>All widths</td><td>6</td><td>57</td></tr><tr><td>w≥0.25µm</td><td>6</td><td>43</td></tr><tr><td>3µm≥w≥0.25µm</td><td>6</td><td>43</td></tr><tr><td rowspan="3">Length≥ 5µm Aspect Ratio ≥ 20</td><td>All widths</td><td>1</td><td>41</td></tr><tr><td>w≥0.25µm</td><td>1</td><td>27</td></tr><tr><td>3µm≥w≥0.25µm</td><td>1</td><td>27</td></tr><tr><td>Length≥ 10µm</td><td>w≤0.25µm</td><td>0</td><td>5</td></tr><tr><td>Length≥ 5µm</td><td>w≤0.5µm</td><td>2</td><td>42</td></tr><tr><td>Length≥ 8µm</td><td>w≤0.25µm</td><td>0</td><td>7</td></tr></table>	Percent of Total Particles				Length and Aspect Ratio	Width	Clev Frag %	Amosite %	Length≥ 5µm Aspect Ratio ≥ 3	All widths	41	64	w≥0.25µm	41	50	3µm≥w≥0.25µm	39	50	Length≥ 5µm Aspect Ratio ≥ 10	All widths	6	57	w≥0.25µm	6	43	3µm≥w≥0.25µm	6	43	Length≥ 5µm Aspect Ratio ≥ 20	All widths	1	41	w≥0.25µm	1	27	3µm≥w≥0.25µm	1	27	Length≥ 10µm	w≤0.25µm	0	5	Length≥ 5µm	w≤0.5µm	2	42	Length≥ 8µm	w≤0.25µm	0	7
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Table 1. Excerpts from Selected References Describing Cleavage Fragments, continued.

Reference	Description
T. Zoltai, "Amphibole Asbestos Mineralogy," <u>Amphiboles and Other Hydrous Pyriboles - Mineralogy</u> , D.R. Veblin editor, Reviews in Mineralogy, Volume 9a, MSA 1981 ^{T1-17} .	P238 The strength of well-developed asbestiform fibers may be as much as 50 times higher than that of single crystals of the same material. P246 Fibers are extremely strong and flexible, while acicular cleavage fragments are weak and brittle. P272 Fibers appear to gain exceptional strength from their surface structures, which are different than their internal structure. The unusual unidirectional growth of the fibers produces continuous and consistent parallel surfaces.
Jack Zussman, "The Crystal Structures of Amphibole and Serpentine Minerals," NBS Special Publication 506, November 1978 ^{T1-18}	P39 The process of stripping fibrils from asbestos is likely to be one of breaking crystallites away from the aggregate at the grain boundaries (between crystallites which are lined up parallel to the fiber axis) across which there is weak cohesion.

Table 2. List of Citations from Relevant Regulations and Analytical Methods

TITLE	REFERENCE	CITED PASSAGE
Regulations, Preambles to Final Rules OSHA	Intro to 29 CFR Parts 1910 and 1926, Occupational Exposure to Asbestos, Tremolite, Anthophyllite and Actinolite (1 of 2) T2-1	"amends the revised asbestos standards (29 CFR Sections 1910.1001 and 1026.58) to remove non-asbestiform tremolite, anthophyllite and actinolite from their scope"
Regulations, Preambles to Final Rules OSHA	Introduction (1 of 4) T2-2	"...discusses OSHA's decision to remove non-asbestiform tremolite, anthophyllite, and actinolite (herein referred to as ATA..."
Regulations, Preambles to Final Rules OSHA	Introduction (1 of 4) T2-3	"OSHA is also removing and reserving 29 CFR 1910.1101, which designated 'Asbestos' and which has been applied to non-asbestiform ATA during the administrative stay..."
Regulations, Preambles to Final Rules OSHA	Introduction (1 of 4) T2-4	"Asbestos and non-asbestiform ATA appear to be distinguishable mineral entities on a population basis, and in most instances on a particle basis"
Regulations, Preambles to Final Rules OSHA	Introduction (3 of 4) T2-5	"Thus, OSHA does not believe that potential asbestos contamination of non-asbestos minerals, including non-asbestiform ATA, is sufficient reason to include such non-asbestiform minerals in the asbestos standard"
Regulations, Preambles to Final Rules OSHA	Introduction (3 of 4) T2-6	"If an identification error is made, it is likely to be a false positive for asbestos rather than a false negative"
Regulations, Preambles to Final Rules OSHA	Pertinent Legal Authority (3 of 4) T2-7	"Thus, the primary basis for including the non-asbestiform varieties of ATA in OSHA's asbestos standards was the Agency's belief that fiber populations with similar 'index' fiber counts, presented essentially the same risk, regardless of whether those 'index' fibers were strictly asbestos in the mineralogical sense"
Regulations, Preambles to Final Rules OSHA	Pertinent Legal Authority (3 of 4) T2-8	"OSHA believed that the primary determinant of biological activity of asbestos is fiber dimension, and that varieties of asbestos minerals of relevant dimension have the same carcinogenic and fibrogenic potential per fiber"
Regulations, Preambles to Final Rules OSHA	Regulatory History (1 of 4) T2-9	"...petitioned OSHA to restrict the application of the 1972 standard so that non-asbestiform anthophyllite and tremolite would not be covered by it. In October 1974 OSHA interpreted the applicability of the asbestos standard to mean only asbestiform tremolite with and aspect ratio of 5 to 1"

Table 2. List of Citations from Relevant Regulations and Analytical Methods, continued.

TITLE	REFERENCE	CITED PASSAGE
Regulations, Preambles to Final Rules OSHA	Regulatory History (2 of 4) T2-10	"In its supplemental proposed rule (49 FR 11416, April 10, 1984)...which regulated only mineralogically correct 'asbestos'"
Regulations, Preambles to Final Rules OSHA	Mineralogical Considerations (2 of 8) T2-11	"Asbestiform is a mineralogical term describing a particular mineral habit. The habit of a mineral is the shape or form a crystal or aggregate of crystals take on during crystallization and is dependent on the existing environmental/geological conditions at the time of formation"
Regulations, Preambles to Final Rules OSHA	Mineralogical Considerations (2 of 8) T2-12	"The term asbestiform is a mineralogical term used to refer to those minerals which are found in a particular mineral habit. That is, while all asbestos is asbestiform, not all asbestiform minerals are asbestos"
Regulations, Preambles to Final Rules OSHA	Mineralogical Considerations (5 of 8) T2-13	"...the width of an asbestos fiber is essentially independent of its length and is not easily altered by processing. In contrast, cleavage fragment populations show increasing width as particle length increases due to the characteristics imparted from normal three dimensional crystal growth"
Regulations, Preambles to Final Rules OSHA	Mineralogical Considerations (5 of 8) T2-14	"Thus OSHA believes that while one can differentiate between mineral types when populations of particles are examined, when single, isolated particles are examined (e.g. particles from air samples) the ability to differentiate may become more difficult"
Regulations, Preambles to Final Rules OSHA	Mineralogical Considerations (8 of 8) T2-15	"Thus although the Agency now reaches a different conclusion than it did in 1986 concerning the evidence of health risks of non-asbestiform ATA, it continues to believe that the mineralogical forms are sufficiently distinctive to be treated differently for regulatory purposes. Also, unlike its determination in 1986, which was based on a far less extensive review of health effects evidence, the Agency now finds that differences in biologic effect between asbestos and its non-asbestiform analogues are likely related to the distinctions which define the two groups as separate mineral entities"
Regulations, Preambles to Final Rules OSHA	Health Effects (9 of 10) T2-16	"... OSHA reaffirms its preliminary determination in the proposal that there is insufficient evidence to conclude that non-asbestiform ATA present a health risk similar in kind and magnitude to that of their asbestiform counterparts"
Regulations, Standards - 29 CFR	Asbestos - 1910.1001(b) Definitions (1 of 31) T2-17	"'Asbestos' includes chrysotile, amosite, crocidolite, tremolite asbestos, anthophyllite asbestos, actinolite asbestos, and any of these minerals that have been chemically treated and/or altered"

Table 2. List of Citations from Relevant Regulations and Analytical Methods, continued.

TITLE	REFERENCE	CITED PASSAGE
Regulations, Standards - 29 CFR	Asbestos - 1910.1001(b) Definitions (2 of 31) T2-18	"'Fiber' means a particulate form of asbestos 5 micrometers or longer, with a length-to-diameter ratio of at least 3 to 1"
Regulations, Standards - 29 CFR	Detailed procedure for asbestos sampling and analysis - Non-Mandatory - 1910.1001 App B (2 of 17) T2-19	"'Asbestos: A term for naturally occurring fibrous minerals. Asbestos includes chrysotile, crocidolite, amosite (cummingtonite-grunerite asbestos), tremolite asbestos, actinolite asbestos, anthophyllite asbestos, and any of these minerals that have been chemically treated and/or altered. The precise chemical formulation of each species will vary with the location from which it was mined. Nominal compositions are listed:
Regulations, Standards - 29 CFR	Detailed procedure for asbestos sampling and analysis - Non-Mandatory - 1910.1001 App B (2 of 17) T2-20	"Asbestos Fiber: A fiber of asbestos which meets the criteria specified below for a fiber"
Regulations, Standards - 29 CFR	Detailed procedure for asbestos sampling and analysis - Non-Mandatory - 1910.1001 App B (2 of 17) T2-21	"Cleavage Fragments: Mineral particles formed by comminution of minerals, especially those characterized by parallel sides and a moderate aspect ratio (usually less than 20:1)"
Regulations, Standards - 29 CFR	Detailed procedure for asbestos sampling and analysis - Non-Mandatory - 1910.1001 App B (2 of 17) T2-22	"Fiber: A particle that is 5 um or longer, with a length-to-width ratio of 3 to 1 or longer"
Regulations, Standards - 29 CFR	Detailed procedure for asbestos sampling and analysis - Non-Mandatory - 1910.1001 App B (3 of 17) T2-23	"...PCM does not positively identify asbestos fibers...Positive identification of asbestos must be performed by polarized light or electron microscopy techniques"
Regulations, Standards - 29 CFR	Detailed procedure for asbestos sampling and analysis - Non-Mandatory - 1910.1001 App B (11 of 17) T2-24	"(5) Count only fibers equal to or longer than 5 um. Measure the length of curved fibers along the curve"

Table 2. List of Citations from Relevant Regulations and Analytical Methods, continued.

TITLE	REFERENCE	CITED PASSAGE
Regulations, Standards - 29 CFR	Detailed procedure for asbestos sampling and analysis - Non-Mandatory - 1910.1001 App B (11 of 17) T2-25	"Alternate differential counting techniques should be used if discrimination is desirable. Differential counting may include primary discrimination based on morphology, polarized light analysis of fibers, or modification of PCM data by Scanning Electron or Transmission Electron Microscopy"
Asbestos in Air	OSHA Method ID-160 (Intro 1 of 15) T2-26	"Asbestos: A term for naturally occurring fibrous minerals. Asbestos includes chrysotile, crocidolite, amosite (cummingtonite-grunerite asbestos), tremolite asbestos, actinolite asbestos, anthophyllite asbestos, and any of these minerals that have been chemically treated and/or altered. The precise chemical formulation of each species will vary with the location from which it was mined"
Asbestos in Air	OSHA Method ID-160 (Intro 2 of 15) T2-27	"Asbestos Fiber: A fiber of asbestos which meets the criteria specified below for a fiber"
Asbestos in Air	OSHA Method ID-160 (Intro 2 of 15) T2-28	"Aspect Ratio: The ratio of the length of a fiber to it's diameter (e.g. 3:1, 5:1 aspect ratios)"
Asbestos in Air	OSHA Method ID-160 (Intro 2 of 15) T2-29	"Cleavage Fragments: Mineral particles formed by comminution of minerals, especially those characterized by parallel sides and a moderate aspect ratio (usually less than 20:1)"
Asbestos in Air	OSHA Method ID-160 (Intro 2 of 15) T2-30	"Fiber: A particle that is 5 um or longer, with a length-to-width ratio of 3 to 1 or longer"
Asbestos in Air	OSHA Method ID-160 (Intro 2 of 15) T2-31	"Tremolite, Anthophyllite, and Actinolite: The non-asbestos form of these minerals which meet the definition of a fiber. It includes any of these minerals that have been chemically treated and/or altered"
Asbestos in Air	OSHA Method ID-160 (1.3 pg 2 of 15) T2-32	"The main disadvantage of PCM is that it does not positively identify asbestos fibers. Other fibers which are not asbestos may be included in the count unless differential counting is performed"
Asbestos in Air	OSHA Method ID-160 (1.5 pg 3 of 15) T2-33	"Asbestos fiber possesses a high tensile strength along its axis, is chemically inert, non-combustible, and heat resistant. It has high electrical resistance and good sound absorbing properties. It can be weaved into cables, fabrics or other textiles, and also matted into asbestos papers, felts, or mats"
Asbestos in Air	OSHA Method ID-160 (6.7 pg 8 of 15) T2-34	"As previously mentioned in Sect. 1.3, PCM does not provide positive confirmation of asbestos fibers. Alternate differential counting techniques should be used if discrimination is desirable. Differential counting may include primary discrimination based on morphology, polarized light analysis of fibers, or modification of PCM data by Scanning Electron or Transmission Electron Microscopy"

Table 2. List of Citations from Relevant Regulations and Analytical Methods, continued.

TITLE	REFERENCE	CITED PASSAGE
Regulations, Standards - 29 CFR	Polarized Light Microscopy of Asbestos--Non-Mandatory - 1910.1001 App J (Intro 1 of 17) T2-35	"Asbestos: A term for naturally occurring fibrous minerals. Asbestos includes chrysotile, crocidolite, amosite (cummingtonite-grunerite asbestos), tremolite asbestos, actinolite asbestos, anthophyllite asbestos, and any of these minerals that have been chemically treated or altered. The precise chemical formulation of each species varies with the location from which it was mined"
Regulations, Standards - 29 CFR	Polarized Light Microscopy of Asbestos--Non-Mandatory - 1910.1001 App J (Intro 2 of 17) T2-36	"Asbestos Fiber: A fiber of asbestos which meets the criteria specified below for a fiber"
Regulations, Standards - 29 CFR	Polarized Light Microscopy of Asbestos--Non-Mandatory - 1910.1001 App J (Intro 2 of 17) T2-37	"Cleavage Fragments: Mineral particles formed by comminution of minerals, especially those characterized by parallel sides and a moderate aspect ratio"
Regulations, Standards - 29 CFR	Polarized Light Microscopy of Asbestos--Non-Mandatory - 1910.1001 App J (Intro 2 of 17) T2-38	"Differential Counting: The term applied to the practice of excluding certain kinds of fibers from a phase contrast asbestos count because they are not asbestos"
Regulations, Standards - 29 CFR	Polarized Light Microscopy of Asbestos--Non-Mandatory - 1910.1001 App J (Intro 2 of 17) T2-39	"Fiber: A particle that is 5 um or longer, with a length-to-width ratio of 3 to 1 or longer. This may include cleavage fragments"
Regulations, Standards - 29 CFR	Polarized Light Microscopy of Asbestos--Non-Mandatory - 1910.1001 App J (1.5 pg 4 of 17) T2-40	"Asbestos minerals belong to two mineral families: the serpentines and the amphiboles. In the serpentine family, the only common fibrous mineral is chrysotile. Occasionally, the mineral antigorite occurs in a fibril habit with morphology similar to the amphiboles. The amphibole minerals consist of a score of different minerals of which only five are regulated by federal standard: amosite, crocidolite, anthophyllite asbestos, tremolite asbestos and actinolite asbestos. These are the only amphibole minerals that have been commercially exploited for their fibrous properties; however, the rest can and do occur occasionally in asbestiform habit"
Regulations, Standards - 29 CFR	Polarized Light Microscopy of Asbestos--Non-Mandatory - 1910.1001 App J (1.7 pg 5 of 17) T2-41	"Compared to cleavage fragments of the same minerals, asbestiform fibers possess a high tensile strength along the fiber axis"
Regulations, Standards - 29 CFR	Polarized Light Microscopy of Asbestos--Non-Mandatory - 1910.1001 App J (3.5 pg 10 of 17) T2-42	"For the purpose of regulation, the mineral must be one of the six minerals covered and must be in the asbestos growth habit... Observation of many fibers is often necessary to determine whether a sample consists of 'cleavage fragments' or of asbestos fibers"

Table 2. List of Citations from Relevant Regulations and Analytical Methods, continued.

TITLE	REFERENCE	CITED PASSAGE
Regulations, Standards - 29 CFR	Polarized Light Microscopy of Asbestos-- Non-Mandatory - 1910.1001 App J (3.5 pg 10 of 17) ^{T2-43}	"Most cleavage fragments of the asbestos minerals are easily distinguishable from true asbestos fibers. This is because true cleavage fragments usually have larger diameters than 1um"
Regulations, Standards - 29 CFR	Polarized Light Microscopy of Asbestos-- Non-Mandatory - 1910.1001 App J (3.5 pg 10 of 17) ^{T2-44}	"Where the particles are less than 1 um in diameter and have an aspect ratio greater than or equal to 3:1, it is recommended that the sample be analyzed by SEM or TEM if there is any question whether the fibers are cleavage fragments or asbestiform particles"
Regulations, Standards - 29 CFR	Polarized Light Microscopy of Asbestos-- Non-Mandatory - 1910.1001 App J (3.5 pg 11 of 17) ^{T2-45}	"True asbestos fibers usually have 0 degrees extinction or ambiguous extinction, while cleavage fragments have more definite extinction"
Electronic Code of Federal Regulations	"Subpart M - National Emission Standard for Asbestos, 40 CFR 61.141" (2 of 5) ^{T2-46}	"...ACM is defined ...as any material containing more than one percent (1%) asbestos as determined using the method specified in App A, Sub F, 40 CFR Part 763 Sect. 1, Polarized Light Microscopy (PLM)"
Electronic Code of Federal Regulations	"Subpart M - National Emission Standard for Asbestos, 40 CFR 61.141" (2 of 5) ^{T2-47}	"...ACM is any asbestos-containing packing, gasket, resilient floor covering or asphalt roofing product which contains more than one percent (1%) asbestos as determined using polarized light microscopy (PLM) according to the method specified in App A, Sub. F, 40 CFR Part 763 (Sect. 61.141)"
Electronic Code of Federal Regulations	Toxic Substance Control Act Regulations 40 CFR Part 763 Ch 1 (763.83 pg 1 of 5) ^{T2-48}	"Asbestos means the asbestiform varieties of: chrysotile (serpentine); crocidolite (riebeckite); amosite (cummingtonite-grunerite); anthophyllite; tremolite; and actinolite"
Electronic Code of Federal Regulations	NESHAP Regulations, 40 CFR Part 61, Ch 1 (61.141 pg 1 of 5) ^{T2-49}	"Asbestos means the asbestiform varieties of serpentine (chrysotile), riebeckite (crocidolite), cummingtonite-grunerite, anthophyllite, and actinolite-tremolite"
Electronic Code of Federal Regulations	"Interim Method of the Determination of Asbestos in Bulk Insulation Samples," 40 CFR Part 763, Ch 1, App E, Sub. E (1.1 pg 1 of 24) ^{T2-50}	"This method is applicable to all bulk samples of friable insulation materials submitted for identification and quantitation of asbestos components"
Electronic Code of Federal Regulations	"Interim Method of the Determination of Asbestos in Bulk Insulation Samples," 40 CFR Part 763, Ch 1, App E, Sub. E (1.7.2.2 pg 4 of 24) ^{T2-51}	"These procedures are not recommended for samples that contain amphibole minerals or vermiculite. Grinding of amphiboles may result in the separation of fiber bundles or the production of cleavage fragments with aspect ratios greater than 3:1. Grinding of vermiculite may also produce fragments with aspect ratios greater than 3:1"

Table 2. List of Citations from Relevant Regulations and Analytical Methods, continued.

TITLE	REFERENCE	CITED PASSAGE
Electronic Code of Federal Regulations	"Interim Method of the Determination of Asbestos in Bulk Insulation Samples," 40 CFR Part 763, Ch 1, App E, Sub. E (1.7.2.3 pg 5 of 24) T2-52	"Table 1-1 lists the above properties for commercial asbestos fibers: Chrysotile (asbestiform serpentine); Amosite (asbestiform grunerite); Crocidolite (asbestiform riebeckite); Anthophyllite-asbestos; Tremolite-actinolite-asbestos"
Electronic Code of Federal Regulations	"Interim Method of the Determination of Asbestos in Bulk Insulation Samples," 40 CFR Part 763, Ch 1, App E, Sub. E (9 of 24) T2-53	Table 2-1 Asbestos Minerals and Their Nonasbestiform Analogs - Asbestiform: Serpentine (Chrysotile), Amphibole (Anthophyllite asbestos, Cumingtonite-grunerite [Amosite], Crocidolite, Tremolite asbestos, Actinolite asbestos)
US Mine Safety and Health Administration	"Exposure Limits for Airborne Contaminants," 30 CFR 57.5001 (1 of 1) T2-54	"(b) The 8-hour time-weighted average airborne concentration of asbestos dust to which employees are exceed 2 fibers per milliliter greater than 5 microns in length, as determined by the membrane filter method magnification (4 millimeter objective) phase contrast illumination...'asbestos' as used herein is limited to the following chrysotile, amosite, crocidolite, anthophyllite asbestos, tremolite asbestos, and actinolite asbestos"
Consumer Product Safety Commission	Definition section of CPSC Regulation, 16 CFR 1304.3 (pg 381) T2-55	"(b) Asbestos means a group of mineral fibers composed of hydrated silicates, oxygen, hydrogen, and other elements such as sodium, iron, magnesium, and calcium in diverse combinations and are: amosite, chrysotile, crocidolite, anthophyllite asbestos, actinolite asbestos, and tremolite asbestos"
NIOSH Manual of Analytical Methods	"Asbestos and Other Fibers by PCM," NIOSH Method 7400 (Measurement 19, Note 2 pg 7 of 15) T2-56	"Although some experienced counters are capable of selectively counting only fibers which appear to be asbestiform, there is presently no accepted method for ensuring uniformity of judgment between laboratories. It is, therefore, incumbent upon all laboratories using this method to report total fiber counts"
NIOSH Manual of Analytical Methods	"Asbestos by TEM," NIOSH Method 7402 (1 of 7) T2-57	"SYNONYMS [CAS#]: actinolite [77536-66-4] or ferroactinolite [15669-07-5]; amosite [12172-73-5]; anthophyllite [77536-67-5]; chrysotile [12001-29-5]; serpentine [18786-24-8]; crocidolite [12001-28-4]; tremolite [77536-68-6]; amphibole asbestos [1332-21-4]"
NIOSH Manual of Analytical Methods	"Asbestos by TEM," NIOSH Method 7402 (1 of 7) T2-58	"This method is used to determine asbestos fibers in the optically visible range and is intended to complement the results obtained by phase contrast microscopy (Method 7400)"

Table 2. List of Citations from Relevant Regulations and Analytical Methods, continued.

TITLE	REFERENCE	CITED PASSAGE
NIOSH Manual of Analytical Methods	"Asbestos by TEM," NIOSH Method 7402 (1 of 7) ^{T2-59}	"INTERFERENCES: Other amphibole particles that have aspect ratios greater than 3:1 and elemental compositions similar to the asbestos minerals may interfere in the TEM analysis. Some non-amphibole minerals may give electron diffraction patterns similar to amphiboles. High concentrations of background dust interfere with fiber identification. Some non-asbestos amphibole minerals may give electron diffraction patterns similar to asbestos amphiboles"
US EPA/ Office of Research and Development	"Analytical Method for Determination of Asbestos Fibers in Water, Eric Chatfield and M. Jane Dillon" (1 of 3) ^{T2-60}	"Asbestos - A commercial term applied to a group of silicate minerals that readily separate into thin, strong fibers that are flexible, heat resistant and chemically inert"
U.S. EPA	"U.S. EPA Drinking Water Methods for Chemical Parameters" (1 of 1) ^{T2-61}	"Method - 100.1 Asbestos by Transmission Electron Microscopy; Title - Analytical Method for the Determination of Asbestos Fibers in Water (EPA/600/4-83-043); Method - 100.2 Asbestos by Transmission Electron Microscopy; Title - Determination of Asbestos Structures Over 10 um in Length in Drinking Water (EPA/600R-94/134)"
Code of Federal Regulations	"Subpart M - National Emission Standard for Asbestos, 40 CFR 61.141" (1 of 1) ^{T2-62}	"Asbestos means the asbestiform varieties of serpentine (chrysotile), riebeckite (crocidolite), cummingtonite-grunerite, anthophyllite, and actinolite-tremolite"
Code of Federal Regulations	"Maximum Contaminant Levels for Inorganic Contaminants, 40 CFR 141.62" (1 of 3) ^{T2-63}	"(2) Asbestos...7 Million Fibers/liter (longer than 10 [mu]m)"
Code of Federal Regulations	"Inorganic Chemical Sampling and Analytical Requirements, 40 CFR 141.23" (2 of 5) ^{T2-64}	"Asbestos...7 MFL \\\...Transmission Electron Microscopy...Detection limit 0.01 MFL"
US Code	"15 U.S.C. 53 Sub. II Sect. 2642 Definitions" (1 of 4) ^{T2-65}	"(3) Asbestos - The term 'asbestos' means asbestiform varieties of chrysotile (serpentine); crocidolite (riebeckite); amosite (cummingtonite-grunerite); anthophyllite; tremolite or actinolite"
US EPA/ Atmospheric Research and Exposure Assessment Laboratory	"Method for the Determination of Asbestos in Bulk Building Materials, R.L. Perkins and B.W. Harvey" (pg A-1) ^{T2-66}	"Asbestiform (morphology) - Said of a mineral that is like asbestos, I.e., crystallized with the habit of asbestos. Some asbestiform minerals may lack the properties which make asbestos commercially valuable, such as long fiber length and high tensile strength. With the light microscope, the asbestiform habit is generally recognized by the following characteristics:"

Table 2. List of Citations from Relevant Regulations and Analytical Methods, continued.

TITLE	REFERENCE	CITED PASSAGE
US EPA/ Atmospheric Research and Exposure Assessment Laboratory	"Method for the Determination of Asbestos in Bulk Building Materials, R.L. Perkins and B.W. Harvey" (pg A-1) ^{T2-67}	* Mean aspect ratios ranging from 20:1 to 100:1 or higher for fibers longer than 5 um. Aspect ratios should be determined for fibers, not bundles"; very thin fibrils, usually less than 0.5 micrometers in width and ...; two or more of the following: parallel fibers occurring in bundles, fiber bundles displaying splayed ends, matted masses of individual fibers, and/or fibers showing curvature
US EPA/ Atmospheric Research and Exposure Assessment Laboratory	"Method for the Determination of Asbestos in Bulk Building Materials, R.L. Perkins and B.W. Harvey" (pg A-1) ^{T2-68}	"These characteristics refer to the population of fibers as observed in a bulk sample. It is not unusual to observe occasional particles having aspect ratios of 10:1 or less, but it is unlikely that the asbestos component(s) would be dominated by particles (individual fibers) having aspect ratios <20:1 for fibers longer than 5um. If a sample contains a fibrous component of which most of the fibers have aspect ratios of <20:1 and that do not display the additional asbestiform characteristics, by definition the component should not be considered asbestos"
US EPA/ Atmospheric Research and Exposure Assessment Laboratory	"Method for the Determination of Asbestos in Bulk Building Materials, R.L. Perkins and B.W. Harvey" (pg A-1) ^{T2-69}	"Asbestos - A commercial term applied to the asbestiform varieties of six different minerals. The asbestos types are chrysotile (asbestiform serpentine), amosite (asbestiform grunerite), crocidolite (asbestiform riebeckite), and asbestiform anthophyllite, asbestiform tremolite, and asbestiform actinolite. The properties of asbestos that caused it to be widely used commercially are: 1) its ability to be separated into long, thin, flexible fibers; 2) high tensile strength; 3) low thermal and electrical conductivity; 4) high mechanical and chemical durability, and 5) high heat resistance"
Code of Federal Regulations	"Mandatory Health Standards, 30 CFR 71.702 Subpart H Airborne Contaminants" (pg 1 of 1) ^{T2-70}	"As used in this subpart, the term asbestos means chrysotile, amosite, crocidolite, anthophyllite asbestos, tremolite asbestos, and actinolite asbestos but does not include nonfibrous or nonasbestiform minerals"
Code of Federal Regulations	"Exposure Limits for Airborne Contaminants," 30 CFR 56.5001 (1 of 1) ^{T2-71}	"Asbestos is a generic term for a number of hydrated silicates that, when crushed or processed, separate into flexible fibers made up of fibrils..."

Table 3. Asbestos Content of the Fine Fraction of Vermiculite Attic Insulation. Asbestos content determined using scanning electron microscopy.

Building	Location	Weight % > 0.5 mm	Weight % < 0.5 mm	Wt. % Asbestos in Fines	Wt% Fine Asbestos in Sample
Marco Barbanti 418 E. Wellesley Spokane, WA	Top	98.82	1.18	0.065	0.0008
	Middle	98.10	1.90	0.314	0.0060
	Bottom	98.24	1.76	0.044	0.0008
	Combined	98.42	1.58	0.146	0.0023
	Top	98.91	1.09	0.105	0.0011
	Middle	98.66	1.34	0.182	0.0024
	Bottom	99.32	0.68	0.465	0.0032
	Combined	98.97	1.03	0.214	0.0022
	Top	98.92	1.08	1.204	0.0129
	Middle	99.49	0.51	0.108	0.0006
	Bottom	99.69	0.31	1.453	0.0045
	Combined	99.32	0.68	0.992	0.0068
Rosie Thurman 1803 W. Knox Spokane, WA	Top	99.67	0.33	0.523	0.0017
	Middle	99.78	0.22	0.781	0.0017
	Bottom	99.68	0.32	0.892	0.0029
	Combined	99.71	0.29	0.737	0.0021
	Top	98.12	1.88	0.071	0.0013
	Middle	98.49	1.51	0.051	0.0008
	Bottom	99.64	0.36	0.109	0.0004
	Combined	98.80	1.20	0.066	0.0008
	Top	95.70	4.30	0.033	0.0014
	Middle	95.49	4.51	0.006	0.0003
	Bottom	97.30	2.70	0.033	0.0009
	Combined	96.16	3.84	0.021	0.0008

Table 3. Asbestos Content of the Fine Fraction of Vermiculite Attic Insulation. Asbestos content determined using scanning electron microscopy, continued.

Building	Location	Weight % > 0.5 mm	Weight % < 0.5 mm	Wt. % Asbestos in Fines	Wt% Fine Asbestos in Sample
Marco Barbanti 1301 W. Malcon Spokane, WA	Top	97.75	2.25	0.813	0.0183
	Middle	98.78	1.22	0.088	0.0011
	Bottom	97.58	2.42	0.030	0.0007
	Combined	98.06	1.94	0.142	0.0028
	Top	98.20	1.80	0.014	0.0003
	Middle	98.46	1.54	0.008	0.0001
	Bottom	98.99	1.01	0.172	0.0017
	Combined	98.62	1.38	0.060	0.0008
Ralph Busch 1512 W 14th Ave Spokane, WA	Top	99.73	0.27	0.245	0.0007
	Middle	99.57	0.43	0.134	0.0006
	Bottom	99.64	0.36	0.553	0.0020
	Combined	99.64	0.36	0.297	0.0011
	Top	99.43	0.57	0.160	0.0009
	Middle	99.60	0.40	0.458	0.0018
	Bottom	99.27	0.73	0.661	0.0048
	Combined	99.43	0.57	0.452	0.0026
Benny King 9909 East Garland Spokane, WA	Debris	97.47	2.53	0.331	0.0084
	Top	97.36	2.64	1.300	0.0344
	Middle	92.76	7.24	0.068	0.0049
	Bottom	92.17	7.83	0.066	0.0052
	Combined	93.36	6.64	0.171	0.0113
	Top	96.87	3.13	0.122	0.0038
	Middle	95.66	4.34	0.134	0.0058
	Bottom	95.07	4.93	0.080	0.0039
	Combined	95.87	4.13	0.111	0.0046

Table 3. Asbestos Content of the Fine Fraction of Vermiculite Attic Insulation. Asbestos content determined using scanning electron microscopy, continued.

Building	Location	Weight % > 0.5 mm	Weight % < 0.5 mm	Wt. % Asbestos in Fines	Wt% Fine Asbestos in Sample
Ernest Matthews 2207 S Adams Rd Veradale, WA	Top	99.26	0.74	0.077	0.0006
	Middle	98.11	1.89	0.009	0.0002
	Bottom	99.37	0.63	0.186	0.0012
	Combined	98.94	1.06	0.061	0.0006
	Top	98.95	1.05	0.003	0.0000
	Middle	96.95	3.05	0.008	0.0002
	Bottom	99.27	0.73	0.102	0.0007
	Combined	98.31	1.69	0.020	0.0003
	Top	97.71	2.29	0.005	0.0001
	Middle	99.67	0.33	0.134	0.0004
	Bottom	99.04	0.96	0.039	0.0004
	Combined	98.85	1.15	0.028	0.0003
Paul Price 3905 Montana Hwy 40 West Columbia Falls, MT	Top	99.13	0.87	0.102	0.0009
	Middle	98.73	1.27	0.118	0.0015
	Bottom	98.70	1.30	0.016	0.0002
	Combined	98.91	1.09	0.085	0.0009
	Top	98.44	1.56	0.030	0.0005
	Middle	94.39	5.61	0.030	0.0017
	Bottom	95.97	4.03	0.049	0.0020
	Combined	96.49	3.51	0.036	0.0013
	Top	99.25	0.75	0.117	0.0009
	Middle	98.47	1.53	0.101	0.0015
	Bottom	97.90	2.10	0.033	0.0007
	Combined	98.36	1.64	0.063	0.0010
John Holbrook 328 South 5th West Missoula, MT 59801	Top	99.25	0.75	0.117	0.0009
	Middle	98.47	1.53	0.101	0.0015
	Bottom	97.90	2.10	0.033	0.0007
	Combined	98.36	1.64	0.063	0.0010

Table 3. Asbestos Content of the Fine Fraction of Vermiculite Attic Insulation. Asbestos content determined using scanning electron microscopy, continued.

Building	Location	Weight % > 0.5 mm	Weight % < 0.5 mm	Wt. % Asbestos in Fines	Wt% Fine Asbestos in Sample
	Top	98.21	1.79	0.132	0.0024
	Middle	98.05	1.95	0.104	0.0020
	Bottom	98.37	1.63	0.213	0.0035
	Combined	98.19	1.81	0.140	0.0025
John Prebil 624 South 5th West Missoula, MT 59801	Top	98.75	1.25	0.302	0.0038
	Middle	97.95	2.05	0.053	0.0011
	Bottom	98.30	1.70	0.342	0.0058
	Combined	98.29	1.71	0.199	0.0034
	Top	98.57	1.43	0.249	0.0036
	Middle	98.36	1.64	0.186	0.0030
	Bottom	97.84	2.16	0.282	0.0061
	Combined	98.16	1.84	0.251	0.0046

Table 4. Ambient Air Concentrations From Samples Collected Indoor and Outdoor At Homes Containing Alleged Zonolite Attic Insulation.

Location		Fibers 5mm				All Fiber Sizes			
		Indoor		Outdoor		Indoor		Outdoor	
Residence	Address	S/mm ²	S/cc	S/mm ²	S/cc	S/mm ²	S/cc	S/mm ²	S/cc
Barbanti	Washington State	0	0	0	0	1.8	0.0003	0	0
Barbanti	Spokane, WA	0	0	0	0	0	0	0	0
Busch	Spokane, WA	0	0	0	0	0	0	0	0
Hatch	Washington State	0	0	0	0	0	0	5.6	0.0010
Holbrook	Missoula, MT	0	0	0	0	0	0	0	0
King	Washington State	0	0	0	0	0	0	0	0
Lindholm	Andover, MA	0	0	0	0	0	0	0	0
Mathews	Washington State	0	0	0	0	0	0	0	0
Prebil	Helena, MT	1.9	0.0004	0	0	1.9	0.0004	0	0
Price	Columbia Falls, MT	0	0	0	0	0	0	0	0
Szufnarowski	Chelmsford, MA	0	0	0	0	0	0	0	0
Thurman	Washington State	0	0	0	0	0	0	0	0

Samples analyzed using AHERA method (40 CFR 763, Appendix A to Subpart E).

Table 5. Summary of Personal Task Concentrations During the Simulations by Lees and Mlynarek, Including Comparative Reduction in Concentration from One Measurement Technique Relative to Another.

Test	Job Title	Time, min	Task Concentrations, f/cc			Reduction in Concentration			
			PCM	PCME Amphibole	PCME Asbestos	PCM / PCME Amphibole	PCM / PCME Asbestos	PCME Amphibole / PCME Asbestos	
General Labor / Cleaning									
1-D	Bystander A	43	0.146	0	0				
1-K	Bystander A	26	0.082	0	0				
1-S	Bystander A	44	0.038	0	0				
1-D	Bystander B	43	0.170	0	0				
1-K	Bystander B	26	0.076	0	0				
1-S	Bystander B	44	0.040	0	0				
1-D	Helper A	42	0.134	0	0				
1-K	Helper A	25	0.123	0	0				
1-S	Helper A	45	0.078	0	0				
1-D	Helper B	42	0.116	0	0				
1-K	Helper B	25	0.136	0	0				
1-S	Helper B	45	0.053	0	0				
1-D	Worker A	42	0.623	0.010	0	62.3	NA	NA	NA
1-K	Worker A	26	0.652	0.147	0	4.4	NA	NA	NA
1-S	Worker A	42	0.353	0.091	0.007	3.9	50.4	13.0	
1-D	Worker B	42	0.510	0.006	0	85.0	NA	NA	NA
1-K	Worker B	26	0.522	0.010	0.010	52.2	52.2	1.0	
1-S	Worker B	42	0.368	0.087	0	4.2	NA	NA	NA
Small Scale Removal									
1-F	Bystander A	21	0.085	0	0				
1-M	Bystander A	11	0.054	0	0				
1-F	Bystander B	21	0.153	0	0				
1-M	Bystander B	11	0.114	0	0				
1-F	Helper A	21	0.105	0	0				
1-M	Helper A	12	0.098	0.586	0.174				
1-F	Helper B	21	0.125	0.010	0				
1-M	Helper B	12	0.301	0.082	0.034				

Table 5. Summary of Personal Task Concentrations During the Simulations by Lees and Mlynarek, Including Comparative Reduction in Concentration from One Measurement Technique Relative to Another, continued.

Test	Job Title	Time, min	Task Concentrations, f/cc				Reduction in Concentration			
			PCM	PCME Amphibole	PCME Asbestos	PCM / PCME Amphibole	PCM / PCME Asbestos	PCME Amphibole / PCME Asbestos		
1-F	Worker A	21	1.233	0.519	0.194	2.4	6.4	2.7		
1-M	Worker A	11	1.699	0.616	0	2.8	NA	NA		
1-F	Worker B	21	1.044	0.571	0.116	1.8	9.0	4.9		
1-M	Worker B	11	1.931	1.216	0.161	1.6	12.0	7.6		
Large Scale Removal										
1-O	Bystander A	24	0.048	0	0					
1-Q	Bystander A	23	0.060	0	0					
1-O	Bystander B	24	0.037	0	0					
1-Q	Bystander B	23	0.055	0	0					
1-O	Helper A	24	0.705	0.518	0.020					
1-Q	Helper A	21	0.502	0.457	0.065					
1-O	Helper B	24	0.678	0.626	0.070					
1-Q	Helper B	21	0.414	0.595	0.066					
1-O	Worker A	24	2.996	2.077	0.389	1.4	7.7	5.3		
1-Q	Worker A	22	2.254	2.006	0.033	1.1	68.3	60.8		
1-O	Worker B	24	2.742	3.185	0.327	0.9	8.4	9.7		
1-Q	Worker B	22	2.003	3.059	0.030	0.7	66.8	102.0		
Renovations										
1-H	Bystander A	167	0.104	0	0					
1-H	Bystander B	167	0.146	0	0					
1-H	Helper A	167	0.140	0.002	0.002					
1-H	Helper B	168	0.112	0	0					
1-H	Worker A	189	0.813	0.324	0.043	2.5	18.9	7.5		
1-H	Worker B	186	0.910	0.196	0.006	4.6	151.7	32.7		

NA - not determined

Table 6. Summary of the Task Concentrations (f/cc) for Various Simulations Related to Vermiculite Attic Insulation

Test/Description	Study	Test	Job Title	PCM	PCME Amphibole	PCME Asbestos
Installation of Insulation						
Dry disturbance of Zonolite Brand Vermiculite; WRM1	Versar	1	unknown	overloaded	0	NA
Dry disturbance of Zonolite Brand Vermiculite; WRM1	Versar	1	unknown	overloaded	0.050	NA
Dry disturbance of Zonolite Vermiculite, Lot# 17K02-1	Versar	2	unknown	0.480	0.398	NA
Dry disturbance of Zonolite Vermiculite, Lot# 17K02-1	Versar	2	unknown	0.312	0.301	NA
Dry disturbance of Zonolite vermiculite, Lot# 6B03-2	Versar	3	unknown	overloaded	0.497	NA
Dry disturbance of Zonolite vermiculite, Lot# 6B03-2	Versar	3	unknown	overloaded	0.549	NA
Dry Disturbance of Zonolite Vermiculite, Lot#21111-2	Versar	4	unknown	0.537	1.463	NA
Dry Disturbance of Zonolite Vermiculite, Lot#21111-2	Versar	4	unknown	0.734	2.637	NA
Dry disturbance of Zonolite Attic Insulation	Versar	5	unknown	0.148	0.150	NA
Dry disturbance of Zonolite Attic Insulation	Versar	5	unknown	0.187	0.301	NA
Dry Disturbance of Strong-Lite; Attic Insulation; Mica Flakes	Versar	6	unknown	0.050	0	NA
Dry Disturbance of Strong-Lite; Attic Insulation; Mica Flakes	Versar	6	unknown	0.061	0	NA
Installation of Vermiculite Attic Insulation	Versar	1	unknown	0.181	0.093	NA
Installation of Vermiculite Attic Insulation	Versar	1	unknown	0.147	0	NA
General Labor/Cleaning						
cleaning	Ewing		Helper	1.620	0	0
cleaning	Ewing		Worker	0.500	0	0
Small Scale Removal						
Residential Activities in the attic	Versar	2	unknown	0.268	0.247	NA
Residential Activities in the attic	Versar	2	unknown	0.229	0.241	NA
Dry Disturbance - No cutting	Versar	1	unknown	1.195	0.200	NA
Dry Disturbance - No cutting	Versar	1	unknown	1.308	2.648	NA
Wet Disturbance -No Cutting	Versar	4	unknown	0.761	0.7	NA
Wet Disturbance -No Cutting	Versar	4	unknown	0.907	1.000	NA
Dry Disturbance - No cutting	Versar	1	unknown	1.841	0.207	NA
Dry Disturbance - No cutting	Versar	1	unknown	1.814	0.405	NA
Wet Disturbance - No cutting	Versar	2	unknown	0.803	0	NA
Wet Disturbance - No cutting	Versar	2	unknown	0.990	0	NA

Table 6. Summary of the Task Concentrations (f/cc) for Various Simulations Related to Vermiculite Attic Insulation, continued.

Test/Description	Study	Test	Job Title	PCM	PCME Amphibole	PCME Asbestos
Large Scale Removal						
removal - WRG	Ewing		Helper	3.200	0	0
removal - homeowner	Ewing		Helper	5.130	1.750	0.096
removal - Shop Vac	Ewing		Helper	2.900	0.220	0.072
removal - WRG	Ewing		Worker	12.560	4.480	0.520
removal - homeowner	Ewing		Worker	14.380	9.570	0.570
removal - Shop Vac	Ewing		Worker	3.050	0.670	0
Removal of Vermiculite Attic Insulation	Versar	3	unknown	0.131	0	NA
Removal of Vermiculite Attic Insulation	Versar	3	unknown	0.115	0.247	NA
Dry Vermiculite -Removal by Homeowner	Versar	7	unknown	0.528	0.400	NA
Dry Vermiculite -Removal by Homeowner	Versar	7	unknown	0.950	0	NA
Dry Vermiculite Removal by homeowner	Versar	5	unknown	0.609	0.301	NA
Dry Vermiculite Removal by homeowner	Versar	5	unknown	0.662	0	NA
Dry Vermiculite - Removal by Contractor	Versar	6	unknown	0.293	0	NA
Dry Vermiculite - Removal by Contractor	Versar	6	unknown	0.093	0	NA
Renovations						
ceiling penetration	Ewing		Helper	5.400	0.680	0.110
ceiling penetration	Ewing		Worker	5.760	0.540	0.050
S-3	US EPA		unknown	0.340	0.128	0.009
Dry disturbance - Hole cut in drywall from attic	Versar	2	unknown	0.931	0	NA
Dry disturbance - Hole cut in drywall from attic	Versar	2	unknown	0.855	0	NA
Dry Disturbance - Hole cut in drywall from living space	Versar	3	unknown	0.891	0.199	NA
Dry Disturbance - Hole cut in drywall from living space	Versar	3	unknown	1.092	0.200	NA
Wet Disturbance -Hole cut in drywall from attic	Versar	5	unknown	1.083	0.497	NA
Wet Disturbance -Hole cut in drywall from attic	Versar	5	unknown	0.928	0.199	NA
Wet Disturbance -Hole cut in drywall from living space	Versar	6	unknown	0.386	0	NA
Wet Disturbance -Hole cut in drywall from living space	Versar	6	unknown	0.462	0	NA
Dry Disturbance - Hole cut in plaster from attic	Versar	3	unknown	1.472	0	NA
Dry Disturbance - Hole cut in plaster from attic	Versar	3	unknown	0.709	0.101	NA

NA - not determined, data not available

Table 7. Dust Sample Concentrations (s/cm²) from Homes with Alleged Zonolite Attic Insulation. Concentrations include Claimants' Expert's reported values and values determined by RJ Lee Group from produced analytical data. "NA" -- data not produced.

Sample Locations	Reported	PCME Amphibole	PCME Asbestos
Walker Home			
Walk boards in attic	44,209	17,004	17,004
Wooden steps of attic access ladder	24,572	0	0
Mason Home (Libby)			
Floor attic apartment storage area	35,175	8,794	8,794
Floor attic apartment storage area	10,978	4,990	0
Spencer Home (Libby)			
Light dust from children's bedroom closet	430	430	0
Medium dust from child's game in closet	6,900	1,386	0
Heavy dust from shelf support in closet	18,600	13,922	0
Loehner Home			
Dust on attic floor near stair case	210,500	NA	NA
Dust from attic flooring in attic wing	14,900	NA	NA
Salisbury Home (Moscow, Idaho)			
Daughter's bedroom closet off cabinet glass door	40,273	20,137	0
Daughter's bedroom closet off the floor	6,653	1,663	0
Dust from carpet in office closet	5,618	2,247	0
Mathews Home: Spokane Washington			
Attic floor (ZAI perimeter only)	26,848	6,712	0
Carpet on attic floor (ZAI in perimeter only)	2,970	1,485	0
On wooden storage box in attic (ZAI in perimeter only)	0	0	0

Table 7. Dust Sample Concentrations (s/cm²) from Homes with Alleged Zonolite Attic Insulation. Concentrations include Claimants' Expert's reported values and values determined by RJ lee Group from produced analytical data. "NA" -- data not produced, continued.

Sample Locations	Reported	PCME Amphibole	PCME Asbestos
Home Silver Spring, MD			
South end of attic off walk boards	99,205	19,841	6,614
North Center from walk boards	34,215	4,888	0
Attic center from walk boards	96,633	22,473	2,247
South end of attic dust under vermiculite pile on walk boards	1,926,619	513,765	0
Barbanti Home (Spokane, WA)			
Dust from under vermiculite	50,300	10,068	0
Dillion Home			
Attic surfaces after home removal 1	1,000,000	NA	NA
Attic surfaces after home removal 2	798,400	NA	NA
Attic surfaces after home removal 3	162,200	NA	NA
Attic surfaces after home removal 4	48,800	NA	NA
Attic surfaces after home removal 5	34,800	NA	NA
Attic surfaces after home removal 6	111,000	NA	NA
MacCready Home			
Attic dust under ZAI 1	604,100	NA	NA
Attic dust under ZAI2	910,200	NA	NA
Busch home			
BD-01	50,789	50,789	0
BD-02	0	0	0
BD-3	205,636	109,672	0

Table 7. Dust Sample Concentrations (s/cm²) from Homes with Alleged Zonolite Attic Insulation. Concentrations include Claimants' Expert's reported values and values determined by RJ Lee Group from produced analytical data. "NA" – data not produced, continued.

Sample Locations	Reported	PCME Amphibole	PCME Asbestos
Mathews Home			
MD-1	6,742	6,742	0
MD-2	38,092	25,395	0
MD-3	0	0	0
MD-4	19,962	0	0
MD-5		0	0
MD-6	0	0	0
MD-7	0	0	0
MD-8	0	0	0
MD-9	0	0	0
MD-10	0	0	0
MD-11	674	674	0
MD-12	333	333	0
MD-13	0	0	0
MD-14	0	0	0
Price Home			
Garage above stairwell to basement	0	0	0
Garage off door mat	0	0	0
Kitchen off door mat to garage	0	0	0
Garage from intake for fireplace	0	0	0
Holbrook Home			
Attic off joist	302,038	100,679	100,679
Attic top of chest	0	0	0
Attic dust from hand railing around staircase	891	891	0